ELECTROSTATIC PRECIPITATORS

COMPLIANCE ASSISTANCE PROGRAM
AIR RESOURCES BOARD

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100 INTRODUCTION

This manual is a product of the California Air Resources Board (CARB). The Air Resources Board was created by the California Legislature to control air pollutant emissions and to improve air quality throughout the State. It works closely with the United States Environmental Protection Agency (EPA) and local air pollution control districts in improving air quality in California.

Particulate Emissions

This manual provides information on electrostatic precipitators (ESPs), which are used as control devices to curtail the emission of particulate matter from a large range of industrial and commercial sources. ESPs and other particulate control devices are installed at facilities to reduce the particulate emissions from these facilities to quantities within the limits prescribed in air pollution regulations. Noncompliance with these regulations often results when the performance of the control devices falters.

Because many areas of California do not attain the State or the national ambient air quality standards for particulate matter, CARB has traditionally sought to reduce noncompliance rates by providing an adequate deterrent through enforcement action against violators. In conjunction with this, CARB now seeks to reduce noncompliance rates and the associated excess emissions by ensuring that the emission source operator has:

1 A basic understanding of the rules to which the source is subject;

2 A basic understanding of how compliance is determined.

CARB established the Compliance Assistance Program (CAP) as a means toward this end.

Continuous Compliance

If California's non-attainment areas are to have any chance of attaining the ambient air quality standards, the excess emissions resulting from non-compliance must be reduced by air pollution control inspectors and industry personnel. Air pollution control inspectors can identify problems for the source operator, but their periodic visits cannot ensure continuous compliance. Ensuring this is the job of educated source operators. The goal of CAP is thus twofold:

1 To help air pollution control districts develop and maintain inspector knowledge;

2 To encourage industry to do self-inspections for continuous compliance.

100 INTRODUCTION

This manual is written for district inspectors and for operators at facilities with ESPs. It is designed to serve district inspectors as a training guide on ESPs and on how to inspect them. It is also designed to supplement the operating manuals that ESP vendors provide their clients. We hope that this manual is detailed enough for the district inspector, and concise enough for the source operator.

Section 200 of this manual describes the rules to which a source with an ESP is subject. Both summaries of rules, and texts of applicable statutes are presented.

Section 300 gives an overview of the theory fundamental to the design of ESPs. It then describes ESP hardware.

Section 400 details inspection procedures for district inspectors. Some of these procedures may be used by source personnel in performing an internal audit.

Section 500 discusses troubleshooting procedures. This section is of greater benefit to source operators than it is to district personnel.

Section 600 lists recommended regular maintenance activities and safety procedures.

References are located in appendix B.

Comment Sheet

CAP welcomes your comments concerning this manual. A comment sheet has been placed at the back of this manual for your convenience. Your comments and corrections, and new information on equipment and processes will be collected and periodically distributed in an upgrade packet. Consequently, your use of the comment sheet will greatly assist us in providing a usable and up-to-date manual.

Tracking Card

A manual tracking card may be found in the front of this manual. It is important that you submit this card to CAP. All changes will be mailed to each person that returns a completed manual tracking card.

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Plants that emit particulate matter are subject to the following requirements:

Rules

1 General prohibitions which include:
   - Visible emissions rule;
   - Particulate matter emissions limit;
   - Fugitive dust emissions;

Permits

2 Permit to Operate;

3 Equipment Breakdown rule.

These requirements are discussed in a separate section of this chapter.

Should the source experience difficulty in complying with these, sources and district personnel should be familiar with the applicable variance provisions.

Federal Standards

In addition, many plants must operate in compliance of the applicable Federal New Source Performance Standards (NSPS).

Capture Efficiency

Electrostatic precipitators (ESPs) are particulate control devices used at many industrial and commercial facilities. An ESP collects particulate matter entrained in a process' effluent gas stream, and keeps most of the particulate matter from being emitted out the stack and into the atmosphere. Many ESPs are designed to capture over 99.9 percent of the particulate matter ducted through them.

When ESPs are operating at or near design standards, the particulate matter passsing out the stack should not be of quantities sufficient to violate the regulatory limits. However, changes in process (such as production rate) and degradation of ESP components over time will alter the particulate emission rate, perhaps pushing it over regulatory limits.

Source operators should have a clear and up-to-date understanding of both the regulatory requirements and the efficiency with which their ESPs are capturing particulate matter. The remainder of this section outlines some of the regulatory requirements.

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201 VISIBLE EMISSIONS

Division 26, Part 4, Chapter 3, Article 1, Section 41701 of the Health and Safety Code of the State of California states:

"... no person shall discharge into the atmosphere from any source whatsoever any contaminant, other than uncombined water vapor, for a period or periods aggregating more than three minutes in any one hour which is:

(a) As dark or darker in shade as that designated as No. 2 on the Ringelmann Chart, as published by the United States Bureau of Mines, or

(b) Of such opacity as to obscure an observer's view to a degree equal to or greater than does smoke described in subdivision (a)."

Many air pollution control districts have more stringent standards (Ringelmann No. 1).

Ringelmann Chart

The Ringelmann Chart is used as a device for determining whether emissions of smoke are within established limits or standards of permissibility (statutes and ordinances) with reference to the Ringelmann Chart. Smoke density in a plume is compared with a series of graduated shades of grey on the Ringelmann Chart, and the smoke density is thus judged by the viewer. EPA Reference Method 9 describes in detail how such visible emission evaluations should be properly performed, and who may perform these. This method is presented in appendix A of this manual.

202 PARTICULATE MATTER EMISSION LIMITS

Air pollution control districts have either a particulate matter by concentration rule or a solid particulate matter by weight rule. Some districts have both rules.

A concentration rule puts limitations on the maximum concentration of particulate matter allowed to be emitted based on the volume flowrate of gas discharged, both being calculated as dry gas at standard conditions.

A solid particulate matter by weight rule limits the maximum discharge rate allowed for solid particulate matter (aggregate weight discharged from all points of a process in one hour) based on the process rate (weight per hour).

For the purposes of these rules, emissions are averaged over one complete cycle of operation or one hour, whichever is the lesser time period.

Typical particulate matter emission-limiting rules are presented in appendix A of this manual.

Appendix A

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203 PERMIT CONDITIONS

Under the authority of the California Health and Safety Code(H&SC), and in order to comply with the California State Implementation Plan and New Source Performance Standards where applicable, the districts issue conditions for the operation of industrial and comercial processes, and the related emission control equipment.

Operating emission sources must function within the parameters stated in the Permit to Operate (PO) issued by the district. Failure to do so is a violation of permit conditions.

The conditions stated on a PO with regard to an electrostatic precipitator vary widely. Some examples are:

1 Limits on the grain loading of stack effluent;

2 Allowable ranges of ESP inlet and outlet temperatures;

3 Minimum total corona power (input);

4 Maximum boiler (process) firing rate;

5 Recordkeeping requirements;

6 Requirements for continuous emission monitors (CEM) regarding calibration, drift, recordkeeping.

7 Maximum pressure drop across the precipitator.

8 Maximum number of fields not energized for whole unit.

9 Maximum number of fields not energized per chamber.

Permits to Operate should be posted in a location per the instructions on the permit or in the district rule.

204 EQUIPMENT BREAKDOWN PROVISIONS

Each district has an equipment breakdown (or excusable equipment malfunction) rule. The rule enables a source qualifying under stated conditions to avoid enforcement action otherwise precipitated by failure of that source to comply with air pollution regulations as a result of a malfunction of any air pollution control equipment or related operating equipment. Malfunctions of in-stack monitoring equipment are also addressed in the rule.

Sources should keep a copy of the breakdown rule on location. They should also be familiar with their responsibilities in the event of an equipment malfunction.

Qualifications for Breakdown Provisions

The conditions that a malfunction must meet in order to qualify for district breakdown provisions vary from district to district. Typically, the following are conditions for an acceptable breakdown:

1 The breakdown must be an unforseeable failure;

2 It must not be the result of neglect or disregard of any air pollution control law or rule or regulation;

3 It must not be intentional, or the result of negligence;

4 It must not be the result of improper maintenance;

5 It must not constitute a nuisance;

6 It must not be an abnormally recurrent breakdown of the same equipment.

District rules also list a number of procedures which must be followed in reporting the breakdown in a timely manner to the district. If the breakdown is not reported to the district within the allowed time period, as stated in the rule, a separate violation occurs, for which enforcement action is appropriate.

When a breakdown is reported to the district, it is recorded in the district's breakdown log. Sources must provide the district with the following information:

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1 The source's name and location, and the source contact's name and telephone number;

2 The specific equipment affected by the breakdown;

3 The specific equipment that failed;

4 The date and time that the breakdown occurred;

5 The date and time that the breakdown is being reported to the district;

6 The source's proposed action.

District Investigation

Upon receipt of a breakdown report, the district performs an investigation to determine whether the malfunction meets the prescribed breakdown conditions. This investigation includes an on-site inspection of the malfunctioning equipment. If the inspector does not find a breakdown condition at the source, he may take appropriate enforcement action including, but not limited to, seeking fines, an abatement order, or an injunction against further operation.

Also, if a source files a breakdown report which falsely, or without probable cause, claims a malfunction to be a breakdown occurrence, then this shall constitute a separate violation. The burden of proof shall be on the source to provide sufficient information that a breakdown did occur. If the source fails to do this, the district will undertake appropriate enforcement action.

Emergency Variance

A source with a breakdown must take immediate steps to correct the equipment malfunction as quickly as possible. If a source finds that a malfunction cannot be repaired within the district's allowable duration of a breakdown, the source may file for an emergency variance in order to avoid enforcement.

District rules require sources to submit in writing the following details to the district control officer within a stated time period of the correction of the breakdown occurrence:

1 The duration of excessive emissions;

2 An estimate of the quantity of excess emissions;

3 A statement of the cause of the occurrence;

4 Corrective measures to be taken to prevent recurrences.

5 Proof of the source's return to compliance, including the date and time that the breakdown was corrected.

Besides the information mentioned above, the district log will also include the following items, some of which will be filled in as the case continues:

1 A confirmation that the breakdown is allowable under district rules;

2 The name of the district investigator;

3 The initial inspection file number;

4 The compliance confirmation inspection file number;

5 The date that the breakdown correction report was filed by the source;

6 An indication if a variance was requested.

205 VARIANCES

A source may petition for a variance if either of the following is true:

1 Pollution control equipment has broken down and meets the criteria for breakdown condition under district rules; however, the source operator finds that it will take longer to repair the breakdown than provided for under the district breakdown rule. In such a case, a source operator may wish to apply for an emergency variance.

2 A source finds itself to be out of compliance, is found to be out of compliance, or expects to soon be out of compliance, with any air pollution control district rule or regulation, or with section 41701 of the California Health and Safety Code (H&SC).

If a source falls into either of the above categories at any time, it should consider applying for a variance. A source's purpose in petitioning for a variance is to attempt to shield itself from enforcement action while it is out of compliance. Sources should be advised that the initiative to file for a variance rests upon them. Table 205.1 provides a quick reference to variance procedures.

When a source applies for a short variance (90 day maximum) or a regular variance (1 year maximum unless a schedule of increments of progress is included), it also applies for an interim variance, which gives the source proctection from enforcement action until the next Hearing Board meeting, or up to a 90 day period, whichever is shorter. Interim and emergency variance orders, if issued, are typically granted the same day they are requested. A written petition must be submitted before these (and all other) variances are granted.

It is the source's responsibility to estimate the amount of time for which it wishes to be under variance, and to then apply for the corresponding type of variance.

Hearing Board

A source should be aware that the decision on whether to grant any variance rests with the district Hearing Board, and not with the air pollution control officer or that person's staff. In general, the more information a source provides to the Hearing Board concerning its compliance problem, the better are its prospects of being granted a variance.

Table 205.1

Variance Quick Reference

Types of Variances	Effective Time Span	Noticing Requirements	Further considerations
Emergency	30 Day Maximum **HSC Section 42359.5**	None **HSC Section 42359.5**	1 member may issue Hearing Board determines eligibility for Emergency **HSC Section 42359.5**
Short	90 Day Maximum **HSC Section 40825**	10 Day Minimum to APCO, Air District, ARB,EPA, and Petitioner **HSC Section 40825**	1 Hearing Board member may hear if District pop. is less than 0.75 million, unless any member of the public objects. **HSC Section 40825**
Interim	90 Day Maximum or until next Hearing Board meeting, whichever occurs first **HSC Section 42351(b)**	Reasonable notice to APCO and Petitioner **HSC Section 40824**	same as Short variance **HSC Section 40824**
Regular	1 year Maximum unless schedule of increments of progress is included **HSC Section 42358**	30 Day Minimum to APCO, Air Basin District, ARB, EPA, Petitioner and any interested member of the public **HSC Section 40826**	Public notice of hearing in at least one newspaper of general circulation in District **HSC Section 40826**
Modification of Final Compliance Date (Extension)	Determined by Hearing Board	same as Regular variance **HSC Section 40826**	same as Regular variance **HSC Section 40826**
Modification of Increments of Progress	Determined by Hearing Board	10 Days Minimum to APCO, Air Basin District, ARB, EPA and petitioner **HSC Section 40825**	same as Interim variance **HSC Section 40825**
Interim Authorization	30 Day Maximum **HSC Section 42351.5**	Reasonable notice to APCO and Petitioner **HSC Section 40824**	No more than one granted application if modification of schedule (May be heard by 1 Hearing Board member if District pop. is less than 0.5 million) **HSC Section 42351.5**

NOTES: HSC Section 42352: to qualify for a variance source must meet six criteria

1. In violation of HSC Section 41701 or District Rules and Regulations
2. Compliance would require unreasonable taking of property or closing or elimination of business
3. Closing or taking would not have significant impact on reducing pollutants
4. Petitioner has considered limiting operation to applying for a variance
5 During the variance, Petitioner will reduce excess emissions to the maximum level feasible
6. Petitioner must quantify or monitor excess emissions while variance is in effect, if requested by the District

HSC Section 42358: Variance must specify an effective time and final compliance date
HSC Section 42360: Copy of the order must be received by ARB within 30 days of granting
HSC Section 42362, 42363: ARB may revoke or modify variance by public hearing and 30 day notice
HSC Section 42356: District Hearing Board may also modify or revoke variance

This table is for quick reference only. Please refer to the Health and Safety Code for complete variance information

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Rules for variance procedures vary somewhat from district to district. The district rules are based on H&SC statutes. Some of the applicable statutes are listed in section 206 of this manual. District personnel as well as source operators should be familiar with these statutes and with the local district variance rule.

With regard to variances, State law (H&SC) requires that:

1 The district should not allow sources to operate in violation of district rules without a variance, even if the source is working towards finding a solution to the problem. Source operators should be aware that under H&SC section 42400.2, if they continue to operate in violation of district rules, they are subject to a $25000 per day fine and up to 12 months in county jail.

2 All variance hearings should be noticed properly in accordance with H&SC sections 40823 through 40827. Section 40826 requires a 30 day notice period for hearings for variances over a 90 day duration.

3 No variance shall be granted unless the Hearing Board makes all of the findings listed in H&SC, section 42352. Notice that parts (d) through (f) were added by the California Clean Air Act, which became effective January 1, 1989. See Table 205.1 for a summary of noticing requirements.

The Air Resources Board recommends the following procedures be observed in the various stages involved from the time a source petitions for a variance, through the end of the variance period. Some of these recommendations may not be a part of all districts' variance programs at this time; or, they may be written but not implemented procedures.

1 Parties petitioning for variances should be required to fill out a petition form in writing.

2 The district will require sources to provide excess emissions figures on the petitions they submit. This information will be evaluated by the District staff. The emission figures are be presented to the Hearing Board, so that the Board formally recognizes, and the public may be aware of, the emissions impact of the variance. If the variance is granted, these limits must be included in the final variance order.

Interim Variance

3 An interim variance should be granted to cover the time period from filing the petition for a regular variance until a decision is rendered if the variance is granted. This interim variance can subject the source to conditions during that interim period.

Not Retroactive

4 Variances should not be granted retroactively. The date that variance coverage begins cannot predate the date on which the petition was filed.

5 Each variance order will specify the equipment under variance, and the district rule or regulation violated. By doing this, protection from enforcement action and the emissions resulting from granting the variance will be limited.

6 The district should schedule increments of progress for sources under variance, and should verify that the source is meeting these.

7 The district should require the source to quantify excess emissions that occur during the period of variance, and report these excess emissions according to a schedule.

District Inspection

8 At the end of the variance period, the district shall inspect the source to ensure that it is in compliance with all district air pollution regulations.

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206 HEALTH AND SAFETY CODE

The following California Health and Safety Code references are included to demonstrate the authority of district air pollution control districts to adopt regulations, issue permit conditions, perform inspections and pursue enforcement action. The relevant Health and Safety Code Sections are presented in numerical order:

39000	Legislative Findings - Environment
39001	Legislative Findings - Agency Coordination
39002	Local and State Agency Responsibilities
39003	ARB Responsibilities
40000	Local/State Responsibilities
40001	Adoption and Enforcement of Rules and Regulations
40702	Adoption of Rules and Regulations
40823	Hearing Board Shall Serve 10 Days Notice
40824	Reasonable Notice for Interim Variance
40825	10 Day Notice for Variances up to 90 Days
40826	30 Day Notice for Regular Variances
41509	No Limitation on Power to Abate Nuisance
41510	Right of Entry With Inspection Warrant
41700	No Person Shall Discharge Pollutants (Public Nuisance)
41701	No Emissions Shall Exceed Ringelmann 2 (Ringelmann/ Opacity Standards)
42300	District Permit System
42301	Requirements For Permit Issuance
42303	Air Contaminant Discharge: Information Disclosure
42303.5	False Statements in Permit Applications
42304	Permit Suspension (Failure to Supply Information)
42350	Applications for Variance
42351	Interim Variance Applications
42351.1	Interim Authorization of Schedule Modification
42352	Findings Required for Issuance of Variance
42353	Other Requirements for Specified Industry, Business, Activity or Individuals
42354	Wide Discretion in Prescribing Requirements
42355	Hearing Board Bond Requirements
42356	Hearing Board Variance Modification or Revocation

39000 LEGISLATIVE FINDINGS - ENVIRONMENT

The Legislature finds and declares that the people of the State of California have a primary interest in the quality of the physical environment in which they live, and that this physical environment is being degraded by the waste and refuse of

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civilization polluting the atmosphere, thereby creating a situation which is detrimental to the health, safety, welfare, and sense of well-being of the people of California.

39001 LEGISLATIVE FINDINGS - AGENCY COORDINATION

The Legislature, therefore, declares that this public interest shall be safeguarded by an intensive, coordinated state, regional, and local effort to protect and enhance the ambient air quality of the state. Since air pollution knows no political boundaries, the Legislature declares that a regional approach to the problem should be encouraged whenever possible and, to this end, the state is divided into air basins. The state should provide incentives for such regional strategies, respecting, when necessary, existing political boundaries.

39002 LOCAL AND STATE AGENCY RESPONSIBILITIES

Local and regional authorities have the primary responsibility for control of air pollution from all sources other than vehicular sources. The control of vehicular sources, except as otherwise provided in this division, shall be the responsibility of the State Air Resources Board. Except as otherwise provided in this division, including, but not limited to, Sections 41809, 41810, and 41904, local and regional authorities may establish stricter standards than those set by law or by the state board for nonvehicular sources. However, the state board shall, after holding public hearings as required in this division, undertake control activities in any area wherein it determines that the local or regional authority has failed to meet the responsibilities given to it by this division or by any other provision of law.

39003 ARB RESPONSIBILITIES

The State Air Resources Board is the state agency charged with coordinating efforts to attain and maintain ambient air quality standards, to conduct research into the causes of and solution to air pollution, and to systematically attack the serious problem caused by motor vehicles, which is the major source of air pollution in many areas of the state.

40000 LOCAL/STATE RESPONSIBILITIES

The Legislature finds and declares that local and regional authorities have the primary responsibility for control of air pollution from all sources, other than emissions from motor vehicles. The control of emissions from motor vehicles, except as otherwise provided in this division, shall be the responsibility of the state board.

40001 ADOPTION AND ENFORCEMENT OF RULES AND REGULATIONS

Subject to the powers and duties of the state board, the districts shall adopt and enforce rules and regulations to achieve and maintain the state and federal ambient air quality standards in all applicable provisions of state and federal law.
The rules and regulations may, and at the request of the state board shall, provide for the prevention and abatement of air pollution episodes which, at intervals, cause discomfort or health risks to, or damage to property of, a significant number of persons or class of persons.

40702 ADOPTION OF RULES AND REGULATIONS

A district shall adopt rules and regulations and do such acts as may be necessary or proper to execute the powers and duties granted to, and imposed upon, the district by this division and other statutory provisions. No order, rule, or regulation of any district shall, however, specify the design of equipment, type of construction, or particular method to be used in reducing the release of air contaminants from railroad locomotives.

40823 HEARING BOARD SHALL SERVE 10 DAYS NOTICE

(a) Except as otherwise provided in Sections 40824, 40825, and 40826, a hearing board shall serve a notice of the time and place of a hearing upon the district air pollution control officer, and upon the applicant or permittee affected, not less than 10 days prior to such hearing.

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(b) Except as otherwise provided in Sections 40824, 40825, and 40826, the hearing board shall also send notice of the hearing to every person who requests such notice and obtain publication of such notice in at least one daily newspaper of general circulation within the district. The notice shall state the time and place of the hearing and such other information as may be necessary to reasonable apprise the people within the district of the nature and purpose of the meeting.

40824 REASONABLE NOTICE FOR INTERIM VARIANCE

In case of a hearing to consider an application for an interim variance, as authorized under Section 42351:
(a) The hearing board shall serve reasonable notice of the time and place of the hearing upon the district air pollution control officer and upon the applicant.
(b) Subdivision (b) of Section 40823 shall not apply.
(c) In districts with a population of less than 750,000, the chairperson of the hearing board, or any other member of the hearing board designated by the board, may hear an application for an interim variance. If any member of the public contests a decision made by a single member of the hearing board, the application shall be reheard by the full hearing board within 10 days of the decision.

40825 10 DAY NOTICE FOR VARIANCES UP TO 90 DAYS

In case of a hearing to consider an application for a variance, or a series of variances, to be in effect for a period of not more than 90 days, or an application for modification of a schedule of increments of progress:
(a) The hearing board shall serve a notice of the time and place of a hearing to grant such a variance or modification upon the air pollution control officer, all other districts within the air basin, the state board, the Environmental Protection Agency, and upon the applicant or permittee, not less than 10 days prior to such hearing.
(b) Subdivision (b) of Section 40823 shall not apply.
(c) In districts with a population of less than 750,000, the chairman of the hearing board, or any other member of the hearing board designated by the board, may hear such an application. If any member of the public contests a decision made by a single member of the hearing board, the application shall be reheard by the full hearing board within 10 days of the decision.

40826 30 DAY NOTICE FOR REGULAR VARIANCES

In case of a hearing to consider an application for a variance, other than an interim variance or a 90-day variance, or an application for a modification of a final compliance date in a variance previously granted, the notice requirements for such a hearing shall be as follows:
(a) The hearing Board shall serve a notice of the time and place of a hearing to grant a variance upon the air pollution control officer, all other districts within the air basin, the state board, the Environmental Protection Agency, and upon the applicant or permittee, not less than 30 days prior to such hearing.
(b) The hearing board shall also publish a notice of the hearing in at least one daily newspaper of general circulation in the district, and shall send the notice to every person who requests such a notice, at least 30 days prior to the hearing.
(c) The notice shall state the time and place of the hearing; the time when, commencing not less than 30 days prior to the hearing, and place where the application, including any proposed conditions or schedule of increments of progress, is available for public inspection; and such other information as may be necessary to reasonably apprise the people within the district of the nature and purpose of the meeting.

41509 NO LIMITATION ON POWER TO ABATE NUISANCE

No provisions of this division, or of any order, rule, or regulation of the state board or of any district, is a limitation on:
(a) The power of any local or regional authority to declare, prohibit, or abate nuisances.
(b) The power of the Attorney General, at the request of a local or regional authority, the state board, or upon his own motion, to bring an action in the name of the people of the State of California to enjoin any pollution or nuisance.
(c) The power of a state agency in the enforcement or administration of any provision of law which it is specifically permitted or required to enforce or administer.
(d) The right of any person to maintain at any time any appropriate action for relief against any private nuisance.

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41510 RIGHT OF ENTRY WITH INSPECTION WARRANT

For the purpose of enforcing or administering any state or local law, order, regulation, or rule relating to air pollution, the executive officer of the state board or any air pollution control officer having jurisdiction, or an authorized representative of such officer, upon presentation of his credentials or, if necessary under the circumstances, after obtaining an inspection warrant pursuant to Title 13 (commencing with Section 1822.50), Part 3 of the Code of Civil Procedure, shall have the right of entry to any premises on which an air pollution emission source is located for the purpose of inspecting such source, including securing samples of emissions therefrom, or any records required to be maintained in connection therewith by the state board or any district.

41700 NO PERSON SHALL DISCHARGE POLLUTANTS (PUBLIC NUISANCE)

Except as otherwise provided in Section 41705, no person shall discharge from any source whatsoever such quantities of air contaminants or other material which cause injury, detriment, nuisance, or annoyance to any considerable number of persons or to the public, or which cause, or have a natural tendency to cause, injury or damage to business or property.

41701 NO EMISSIONS SHALL EXCEED RINGELMANN 2 (RINGELMANN/ OPACITY STANDARDS)

Except as otherwise provided in Section 41704, or Article 2 (commencing with Section 41800) of this chapter other than Section 41812, or Article 2 (commencing with Section 42350) of Chapter 4, no person shall discharge into the atmosphere from any source whatsoever any air contaminant, other than uncombined water vapor, for a period or periods aggregating more than three minutes in any one hour which is:

(a) As dark or darker in shade as that designated as No. 2 on the Ringelmann Chart, as published by the United States Bureau of Mines, or

(b) Of such opacity as to obscure an observer's view to a degree equal to or greater than does smoke described in subdivision (a).

42300 DISTRICT PERMIT SYSTEM

Every district board may establish, by regulation, a permit system that requires, except as otherwise provided in Section 42310, that before any person builds, erects, alters, replaces, operates, or uses any article, machine, equipment, or other contrivance which may cause the issuance of air comtaminants, such person obtain a permit to do so from the air pollution control officer of the district.

The regulations may provide that a permit shall be valid only for a specific period. However, a permit shall be renewable upon payment of the fees required pursuant to Section 42311, except where action to suspend or revoke the permit has been initiated pursuant to Section 42304, 42307, or 42309, and such action has resulted in a final determination to suspend or revoke the permit by the air pollution control officer if the hearing board by whom, or before whom, such action has been initiated and all appeals, or time for appeals, from such final determination has been exhausted.

42301 REQUIREMENTS FOR PERMIT ISSUANCE

A permit system established pursuant to Section 42300 shall do all of the following:
(a) Ensure that the article, machine, equipment, or contrivance for which the permit was issued shall not prevent or interfere with the attainment or maintenance of any applicable air quality standard.
(b) Prohibit the issuance of a permit unless the air pollution control officer is satisfied, on the basis of criteria adopted by the district board, that the article, machine, equipment, or contrivance will comply with all applicable orders, rules, and regulations of the district and of the state board and with all applicable provisions of this division.
(c) Require, upon annual renewal, that each permit be reviewed to determine that permit conditions are adequate to ensure compliance with, and the enforcement of, district rules and regulations applicable to the article, machine, equipment, or contrivance for which the permit was issued which were in effect at the time the permit was issued or modified, or which have subsequently been adopted and made retroactively applicable to an existing article, machine, equipment, or contrivance, by the district board and, if the conditions are not consistent, require that the permit be revised to specify the permit conditions in

accordance with all applicable rules and regulations.
(d) Provide for the reissuance or transfer of a permit to a new owner or operator of an article, machine, equipment, or contrivance. An application for transfer of ownership only, or change in operator only, of any article, machine, equipment, or contrivance which had a valid permit to operate within the two-year period immediately preceding the application is a temporary permit to operate. Issuance of the final permit to operate shall be conditional upon a determination by the district that the criteria specified in subdivisions (b) and (c) are met, if the permit was not surrendered as a condition to receiving emission reduction credits pursuant to banking or permitting rules of the district. However, under no circumstances shall the criteria specify that a change of ownership or operator alone is a basis for requiring more stringent emission controls or operating conditions than would otherwise apply to the article, machine, equipment, or contrivance.

42303 AIR CONTAMINANT DISCHARGE: INFORMATION DISCLOSURE

An air pollution control officer, at any time, may require from an applicant for, or the holder of, any permit provided for by the regulations of the district board, such information, analyses, plans, or specifications which will disclose the nature, extent, quantity, or degree of air contaminants which are, or may be, discharged by the source for which the permit was issued or applied.

42303.5 FALSE STATEMENTS IN PERMIT APPLICATIONS

No person shall knowingly make any false statement in any application for a permit, or in any information, analyses, plans, or specifications submitted in conjunction with the application or at the request of the air pollution control officer.

42304 PERMIT SUSPENSION (FAILURE TO SUPPLY INFORMATION)

If, within a reasonable time, the holder of any permit issued by a district board willfully fails and refuses to furnish the information, analyses, plans, or specifications requested by the district air pollution control officer, such officer may suspend the permit. Such officer shall serve notice in writing of such suspension and the reasons therefor on the permittee.

42350 APPLICATIONS FOR VARIANCE

Any person may apply to the hearing board for a variance from Section 41701 or from the rules and regulations of the district.
However, if the district board established a permit system by regulating pursuant to Section 42300, a variance may not be granted from the requirement for a permit to build, erect, alter, or replace.

42351 INTERIM VARIANCE APPLICATIONS

(a) Any person who has submitted an application for a variance and who desires to commence or continue operation pending the decision of the hearing board on the application, may submit an application for an interim variance.
(b) An interim variance may be granted for good causes stated in the order granting such a variance. The interim variance shall not be valid beyond the date of decision of the hearing board on the application of the variance or for more than 90 days from date of issuance of the interim variance, whichever occurs first.
(c) The hearing board shall not grant any interim variance (1) after it has held a hearing in compliance with the requirements of Section 40826, or (2) which is being sought to avoid the notice and hearing requirements of Section 40826.

42351.5 INTERIM AUTHORIZATION OF SCHEDULE MODIFICATION

If a person granted a variance with a schedule of increments of progress file an application for modification of the schedule and is unable to notify the hearing board sufficiently in advance to allow the hearing board to schedule a public hearing on the application, the hearing board may grant no more than one interim authorization valid for not more than 30 days, to that person to continue operation pending the decision of the hearing board on the application. In districts with a population of less than 500,000, the chairman of the hearing board or any other member designated by the board may hear such application.

If any member of the public contests such a decision made by a single member of the hearing board, the application shall be reheard by the full hearing board within 10 days of the decision. The interim, authorization shall not be granted for a requested extension of a final compliance date or where the original variance expressly required advance application for the modification of an increment of progress.

42352 FINDINGS REQUIRED FOR ISSUANCE OF VARIANCE

No variance shall be granted unless the hearing board makes all of the following findings:
(a) That the petitioner for a variance is, or will be, in violation of Section 41701 or of any rule, regulation, or order of the district.
(b) That, due to conditions beyond the reasonable control of the petitioner, requiring compliance would result in either (1) an arbitrary or unreasonable taking of property, or (2) the practical closing and elimination of a lawful business.
(c) That the closing or taking would be without a corresponding benefit in reducing air contaminants.
(d) That the applicant for the variance has given consideration to curtailing operations of the source in lieu of obtaining a variance.
(e) During the period the variance is in effect, that the applicant will reduce excess emissions to the maximum extent feasible.
(f) During the period the variance is in effect, that the applicant will monitor or otherwise quantify emission levels from the source, if requested to do so by the district, and report these emissions levels to the district pursuant to a schedule established by the district.

42353 OTHER REQUIREMENTS FOR SPECIFIED INDUSTRY, BUSINESS, ACTIVITY OR INDIVIDUALS

Upon making the specific findings set forth in Section 42352, the hearing board shall prescribe requirements other than those imposed by statute or by any rule, regulation, or order of the district board, not more onerous, applicable to plants and equipment operated by specified industry or business or for specified activity, or to the operations of individual persons. However, no variance shall be granted if the operator, under the variance, will result in a violation of Section 41700.

42354 WIDE DISCRETION IN PRESCRIBING REQUIREMENTS

In prescribing other and different requirements, in accordance with Section 42353, the hearing board, insofar as is consonant with the Legislature's declarations in Sections 39000 and 39001, shall exercise a wide discretion in weighing the equities involved and the advantages to the residents of the district from the reduction of air contaminants and the disadvantages to any otherwise lawful business, occupation, or activity involved, resulting from requiring compliance with such requirements.

42355 HEARING BOARD BOND REQUIREMENTS

(a) The hearing board may require, as a condition of granting a variance, that a bond be posted by the party to whom the variance was granted to assure performance of any construction, alteration, repair, or other work required by the terms and conditions of the variance. The bond may provide that, if the party granted the variance fails to perform the work by the agreed date, the bond shall be forfeited to the district having jurisdiction, or the sureties shall have the option of promptly remedying the variance default or paying to the district an amount, up to the amount specified in the bond, that is necessary to accomplish the work specified as a condition of the variance.
(b) The provisions of this section do not apply to vessels so long as the vessels are not operating in violation of any federal law enacted for the purpose of controlling emissions from combustion of vessel fuels.

42356 HEARING BOARD VARIANCE MODIFICATION OR REVOCATION

The hearing board may modify or revoke, by written order, any order permitting a variance.

200 RULE DISCUSSION

42357 HEARING BOARD REVIEW OF SCHEDULE OF INCREMENTS OF PROGRESS OR FINAL COMPLIANCE DATE

The hearing board may review and for good cause, such as a change in the availability of materials, equipment, or adequate technology, modify a schedule of increments of progress or a final compliance date in such a schedule.

42358 EFFECTIVE PERIOD OF ORDER, FINAL COMPLIANCE DATE

(a) The hearing board, in making any order permitting a variance, shall specify the time during which such order shall be effective, in no event, except as otherwise provided in subdivision (b), to exceed one year, and shall set a final compliance date.
(b) A variance may be issued for a period exceeding one year if the variance includes a schedule of increments of progress specifying a final compliance date by which the emissions of air contaminants of a source for which the variance is granted will be brought into compliance with applicable emission standards.

42359 PUBLIC HEARING REQUIREMENTS, EMERGENCY EXCEPTIONS

Except in the case of an emergency, as determined by the hearing board, the hearing board shall hold a hearing pursuant to Chapter 8 (commencing with Section 40800) of Part 3 to determine under what conditions, and to what extent, a variance shall be granted.

42359.5 EMERGENCY VARIANCES

(a) Notwithstanding any other provision of this article or of Article 2 (commencing with Section 40820) of Chapter 8 of Part 3, the Chairman of a district hearing board, or any other member of the hearing board designated thereby, may issue, without notice and hearing, an emergency variance to an applicant.
(b) An emergency variance may be issued for good cause, including, but not limited to, a breakdown condition. The district board in consultation with its air pollution control officer and the hearing board may adopt rules and regulations,

not inconsistent with this subdivision, to further specify the conditions, and to what extent, an emergency variance may be granted.

The emergency variance shall not remain in effect longer than 30 days and shall not be granted when sought to avoid the provisions of Section 40824 or 42351.

42360 COPY OF VARIANCE ORDER TO ARB

Within 30 days of any order granting, modifying, or otherwise affecting a variance by the hearing board, or a member thereof pursuant to Section 42359.5, either the air pollution control officer or the hearing board shall submit a copy of the order to the state board.

42361 VALIDITY OF VARIANCE TIME

Any variance granted by the hearing board of a county district or a unified district, or any member of such a hearing board pursuant to Section 42359.5, applicable in an area which subsequently becomes included within a regional district, including the bay district, shall remain valid for the time specified therein or for one year, whichever is shorter, or, unless prior to the expiration of such time, the hearing board of the regional district modifies or revokes the variance.

42362 VARIANCE REVOCATION OR MODIFICATION

The state board may revoke or modify any variance granted by any district if, in its judgement, the variance does not require compliance with a required schedule of increments of progress or emission standards as expeditiously as practicable, or the variance does not meet the requirements of this article.

42363 ARB HEARING PRIOR TO ACTION

Prior to revoking or modifying a variance pursuant to Section 42362, the state board shall conduct a hearing pursuant to Chapter 8 (commencing with Section 40800) of Part 3 on the matter. The person to whom the variance was granted shall be given immediate notice of any such hearing by the hearing board, and shall be afforded an opportunity to appear at the hearing, to call and examine witnesses, and to otherwise partake as if he were a party to the hearing.

42364 SCHEDULE OF FEES

(a) The district board may adopt, by regulation, a schedule of fees which will yield a sum not exceeding the estimated cost of the administration of this article and for the filing of applications for variances or to revoke or modify variances. All applicants shall pay the fees required by the schedule, including, notwithstanding the provisions of Section 6103 of the Government Code, an applicant that is a publicly owned public utility.
(b) All such fees shall be paid to the district treasurer to the credit of the district.

42400 GENERAL VIOLATIONS, CRIMINAL

(a) Except as otherwise provided in Section 42400.1 or 42400.2, any person who violates any provision of this part, or any order, permit, rule, or regulation of the state board or of a district, including a district hearing board, adopted pursuant to Part 1 (commencing with Section 3900) to Part 4 (commencing with Section 41500), inclusive, is guilty of a misdemeanor and is subject to a fine of not more than one thousand dollars ($1,000) or imprisonment in the county jail for not more than six months, or both.

(b) If a violation under subdivision (a) with regard to the failure to operate a vapor recovery system on a gasoline cargo tank is directly caused by the actions of an employee under the supervision of, or of any independent contractor working for, any person subject to this part, the employee or independent contractor, as the case may be, causing the violation is guilty of a misdemeanor and is punishable as provided in subdivision (a). That liability shall not extend to the person employing the employee or retaining the independent contractor, unless that person is separately guilty of any action violating any provision of this part.

(c) The recovery of civil penalties pursuant to Section 42402, 42402.1, or 42402.2, precludes prosecution pursuant to this section for the same offense. When a district refers a violation to a prosecuting agency, the filing of a criminal complaint is grounds requiring the dismissal of any civil action brought pursuant to this article for the same offense.

(d) Each day during any portion of which a violation of subdivision (a) occurs is a separate offense.

42400.1 NEGLIGENCE, CRIMINAL

(a) Any person who negligently emits an air contaminant in violation of any provision of this part or any rule, regulation, or order of the state board or of a district pertaining to emission regulations or limitations is guilty of a misdemeanor and is subject to a fine of not more than ten thousand dollars ($10,000) or imprisonment in the county jail for not more than nine months, or both.

(b) Any person who owns or operates any source of air contaminant in violation of Section 41700 which causes actual injury, as defined in subdivision (c) of Section 42400.2, to the health or safety of a considerable number of persons or the public is guilty of a misdemeanor and is punishable as provided in subdivision (a).

(c) Each day during any portion of which a violation occurs is a separate offense.

(d) The recovery of civil penalties pursuant to Section 42402, 42402.1, or 42402.2. precludes prosecution pursuant to this section for the same offense. When a district refers a violation to a prosecuting agency, the filing of a criminal complaint is grounds requiring the dismissal of any civil action brought pursuant to this article for the same offense.

42400.2 DOCUMENT FALSIFICATION OR FAILURE TO TAKE CORRECTIVEACTION, CRIMINAL

(a) Any person who emits an air contaminant in violation of any provision of this part, or any order, rule, or regulation of the state board or of a district pertaining to emission regulations or limitations, and who knew of the emission and failed to take corrective action within a reasonable period of time under the circumstances, is guilty of a misdemenanor and is subject to a fine of not more than twenty-five thousand dollars ($25,000) or imprisonment in the county jail for not more than one year, or both.

For purposes of this section, "corrective action" means the termination of the emission violation or the grant of a variance from the applicable order, rule, or regulation pursuant to Article 2 (commencing with Section 42350). If a district regulation regarding process upsets or equipment breakdowns would allow continued operation of equipment which is emitting air contaminants in excess of allowable limits, compliance with that regulation is deemed to be corrective action.

(b) Any person who, knowingly and with intent to deceive, falsifies any document required to be kept pursuant to any provision of this part, or any rule, regulation, or order of the state board or of a district, is guilty of a misdemeanor and is punishable as provided in subdivision (a).

(c) Any person who owns or operates any source of air contaminants in violation of Section 41700 which causes actual injury to the health or safety of a considerable number of persons or the public, and who knew of the emission and failed to take corrective action, as defined in subdivision (a), within a reasonable period of time under the circumstances, is guilty of a misdemeanor and is punishable as provided in subdivision (a).

As used in this subdivision, "actual injury" means any physical injury which, in the opinion of a licensed physician and surgeon, requires medical treatment involving more than a physical examination.

(d) Each day during any portion of which a violation occurs constitutes a separate offense.

(e) The recovery of civil penalties pursuant to Section 42402, 42402.1, or 42402.2, precludes prosecution pursuant to this section for the same offense. When a district refers a violation to a prosecuting agency, the filing of a criminal complaint is grounds requiring the dismissal of any civil action brought pursuant to this article for the same offense.

42401 VIOLATING ORDER OF ABATEMENT, CIVIL

Any person who intentionally or negligently violates any order of abatement issued by a district pursuant to Section 42450, by a hearing board pursuant to Section 42451, or by the state board pursuant to Section 41505 is liable for a civil penalty of not more than twenty-five thousand dollars ($25,000) for each day in which the violation occurs.

42402 GENERAL VIOLATIONS, CIVIL

(a) Except as otherwise provided in Section 42402.1 or 42402.2, any person who violates any provision of this part, or any order issued pursuant to Section 42316, or any order, permit, rule, or regulation of a district, including a district hearing board, or of the state board issued pursuant to Part 1 (commencing with Section 39000) to Part 4 (commencing with Section 41500), inclusive, is liable for a civil penalty of not more than one thousand dollars ($1,000).

(b) There is no liability under subdivision (a) if the person accused of the violation alleges by affirmative defense and establishes that the violation was caused by an act which was not the result of intentional or negligent conduct.

(c) Each day during any portion of which a violation occurs is a separate offense.

42402.1 NEGLIGENCE OR ACTUAL INJURY, CIVIL

(a) Any person who negligently emits an air contaminant in violation of this part or any rule, regulation, or order of the state board or of a district pertaining to emission regulations or limitations is liable for a civil penalty of not more than ten thousand dollars ($10,000).

(b) Any person who owns or operates any source of air contaminants in violation of Section 41700 which causes actual injury, as defined in subdivision (c) of Section 42400.2, to the health or safety of a considerable number of persons or the public is liable for a civil penalty as provided in subdivision (a).

(c) Each day during any portion of which a violation occurs is a separate offense.

42402.2 DOCUMENT FALSIFICATION OR FAILURE TO TAKE CORRECTIVE ACTION, CIVIL

(a) Any person who emits an air contaminant in violation of any provision of this part, or any order, rule, or regulation of the state board or of a district pertaining to emission regulations or limitations, and who knew of the emission and failed to take corrective action within a reasonable period of time under the circumstances, is liable for a civil penalty, of not more than twenty-five thousand dollars ($25,000).

For purposes of this section, "corrective action" means the termination of the emission violation or the grant of a variance from the applicable order, rule, or regulation pursuant to Article 2 (commencing with Section 42350). If a district regulation regarding process upsets or equipment breakdowns would allow continued operation of equipment which is emitting air contaminants in excess of allowable limits, compliance with that regulation is deemed to be corrective action.

(b) Any person who, knowingly and with intent to deceive, falsifies any document required to be kept pursuant to any provision of this part, or any rule, regulation, or order of the state board or of a district, is subject to the same civil penalty as provided in subdivision (a).

(c) Any person who owns or operates any source of air contaminants in violation of Section 41700 which causes actual injury to the health or safety of a considerable number of persons or the public, and who knew of the emission and failed to take corrective action, as defined in subdivision (a), within a reasonable period of time under the circumstances, is subject to a civil penalty as provided in subdivision (a).

As used in this subdivision, "actual injury" means any physical injury which, in the opinion of a licensed physician and surgeon, requires medical treatment involving more than a physical examination.

(d) Each day during any portion of which a violation occurs is a separate offense.

42402.5 GENERAL VIOLATIONS, ADMINISTRATIVE CIVIL (ADMINISTRATIVE PENALTIES)

In addition to any civil and criminal penalties prescribed under this article, a district may impose administrative civil penalties for a violation of this part, or any order, permit, rule, or regulation of the state board or of a district, including a district hearing board, adopted pursuant to Part 1 (commencing with Section 39000) to Part 4 (commencing with Section 41500), inclusive, if the district board has adopted rules and regulations specifying procedures for the imposition and amounts of these penalties. No administrative civil penalty levied pursuant to this section may exceed five hundred dollars ($500) for each violation. However, nothing in this section is intended to restrict the authority of a district to negotiate mutual settlement under any other penalty provision of law which exceeds five hundred dollars ($500).

42403 RECOVERY OF CIVIL PENALTIES (PROCEDURES/ CONSIDERATIONS)

The civil penalties prescribed in Sections 42401, 42402, 42402.1, and 42402.2 shall be assessed and recovered in a civil action brought in the name of the people of the State of California by the Attorney General, by any district attorney, or by the attorney for any district in which the violation occurs in any court of competent jurisdiction.

In determining the amount assessed pursuant to Sections 42401, 42402, 42402.1, and 42402.2, the court shall take into consideration all relevant circumstances, including, but not limited to, the following:

(a) The extent of harm caused by the violation.
(b) The nature and persistence of the violation.
(c) The length of time over which the violation occurs.
(d) The frequency of past violations.
(e) The record of maintenance.
(f) The unproven or innovative nature of the control equipment.

(g) Any action taken by the defendant to mitigate the violation.
(h) The financial burden to the defendant.

42404.5 STATUTE OF LIMITATIONS FOR CIVIL ACTIONS

Any limitation of time applicable to actions brought pursuant to Section 42403 shall not commence to run until the offense has been discovered, or could reasonably have been discovered.

42450 ORDERS OF ABATEMENT DISTRICT BOARD; AUTHORITY; NOTICE AND HEARING

The district board may, after notice and a hearing, issue an order for abatement whenever it finds that any person is constructing or operating any article, machine, equipment, or other contrivance without a permit required by this part, or is in violation of Section 41700 or 41701 or of any order, rule, or regulation prohibiting or limiting the discharge of air contaminants into the air.

In holding such a hearing, the district board shall be vested with all the powers and duties of the hearing board. Notice shall be given, and the hearing shall be held, pursuant to Chapter 8 (commencing with Section 40800) of Part 3.

42700 MONITORING DEVICES - LEGISLATIVE FINDINGS AND DECLARATIONS

The Legislature hereby finds and declares that stationary sources of air pollution are known to emit significant amounts of pollutants into the air, but that existing sampling techniques are not sufficiently precise to permit accurate measurement. The Legislature further finds and declares that more accurate data will improve the design of strategies for the control of such pollutants in the most cost-effective manner.

The Legislature further finds and declares that public complaints about excessive emissions from stationary sources are difficult or impossible to evaluate in the absence of adequate means of monitoring such emissions on a continuing basis. The Legislature further finds and declares that, although the state board and the districts are authorized under Sections 41511 and 42303, to require stationary sources of air contaminants to install and operate monitoring devices to measure and record continuously the emissions concentration and amount of any specified pollutant, many districts have failed to exercise such authority.

The Legislature further finds and declares that all districts, especially the bay district, the districts located, in whole or part, within the South Coast Air Basin, and the San Diego County Air Pollution Control District, should be encouraged to require that monitoring devices be installed in each stationary source of air contaminants which emits into the atmosphere 100 tons or more each year of non-methane hydrocarbons, oxides of nitrogen, oxides of sulfur, reduced sulfur compounds, or particulate matter or 1,000 tons or more each year of carbon monoxide.

In order to encourage such action by the districts, the state board shall determine the availability, technological feasibility, and economic reasonableness of monitoring devices for such stationary sources as provided by Section 42701.

42701 DETERMINATION OF AVAILABILITY, TECHNOLOGICAL FEASIBILITY, AND ECONOMIC REASONABLENESS

(a) For the purpose of Sections 41511 and 42303, the state board shall determine the availability, technological feasibility, and economic reasonableness of monitoring devices to measure and record continuously the emissions concentration and amount of nonmethane hydrocarbons, oxides of nitrogen, oxides of sulfur, reduced sulfur compounds, particulate matter, and carbon monoxide emitted by stationary sources. Such determination shall be made for stationary sources which emit such contaminants in the quantities set forth in Section 42700, and may be made for stationary sources which emit lesser amounts. The state board shall complete an initial review of submitted devices by June 1, 1975.

42702 SPECIFICATION OF TYPES OF STATIONARY SOURCES, PROCESSES AND CONTAMINANTS

The state board shall specify the types of stationary sources, processes, and the contaminants, or combinations thereof, for which a monitoring device is available, technologically feasible, and economically reasonable. Such specification may be by any technologically based classification, including on an industry-wide basis or by individual stationary source, by air basin, by district, or any other reasonable classification.

42703 REIMBURSEMENTS FOR ACTUAL TESTING EXPENSES

The state board shall require the manufacturer of any monitoring device submitted for a determination to reimburse the state board for its actual expenses incurred in making the determination, including, where applicable, its contract expenses for testing and review.

42704 DETERMINATION OF AVAILABILITY; REVOCATION OR SUSPENSION

After the state board has made a determination of availability, the state board may, as appropriate, revoke or modify its prior determination of availability if circumstances beyond the control of the state board, or of a stationary source required to install a monitoring device, cause a substantial delay or impairment in the availability of the device or cause the device no longer to be available.

42705 RECORDS

Any stationary source required by the district in which the source is located to install and operate a monitoring device shall retain the records from the device for not less than two years and, upon request, shall make the records available to the state board and the district.

42706 REPORT OF VIOLATION OF EMISSION STANDARD

Any violation of any emission standard to which the stationary source is required to conform, as indicated by the records of the monitoring device, shall be reported by the operator of the source to the district within 96 hours after such occurrence. The district shall, in turn, report the violation to the state board within five working days after receiving the report of the violation from the operator.

42707 INSPECTION; FEES

The air pollution control officer shall inspect, as he determines necessary, the monitoring devices installed in every stationary source of air contaminants located within his jurisdiction required to have such devices to insure that such devices are functioning properly. The district may require reasonable fees to be paid by the operator of any such source to cover the expense of such inspection and other costs related thereto.

42708 POWERS OF LOCAL OR REGIONAL AUTHORITY

This chapter shall not prevent any local or regional authority from adopting monitoring requirements more stringent than those set forth in this chapter or be construed as requiring the installation of monitoring devices on any stationary source or classes of stationary sources. This section shall not limit the authority of the state board to require the installation of monitoring devices pursuant to Chapter 1 (commencing with Section 41500).

300 THEORY AND DESIGN

This section of the manual is written chiefly for air pollution control district inspectors. The reader is provided with a basic understanding of the electrostatic precipitation process: electrostatic precipitator (ESP) design types, components and instrumentation; and various design factors that affect ESP performance.

An ESP uses an electric field to charge and collect particles from an effluent gas stream. Electrostatic precipitation as a method of particulate control consists of three basic processes:

1 Charging of particles in the gas stream, using positively or negatively charged electrodes;

2 Collection of the charged particles on electrodes using oppositely charged (or grounded) electrodes;

3 Removal of the collected particles from the collection electrodes.

Section 301 describes mechanisms used to charge particulate matter entrained in the gas stream.

300 THEORY AND DESIGN

301 CHARGING MECHANISMS

Single-stage precipitators, or Cottrell precipitators, are so named because the charging and collection of particles are carried out in one stage, as shown in figure 301.1. In two-stage or Penney precipitators, these functions are arranged in separate stages, as shown in figure 301.2.

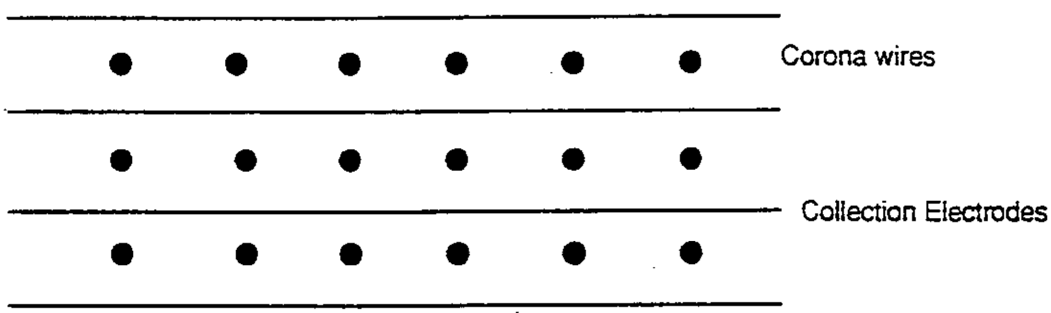


Figure 301.1 Charging and Collection Process for Single-Stage ESPs[20]

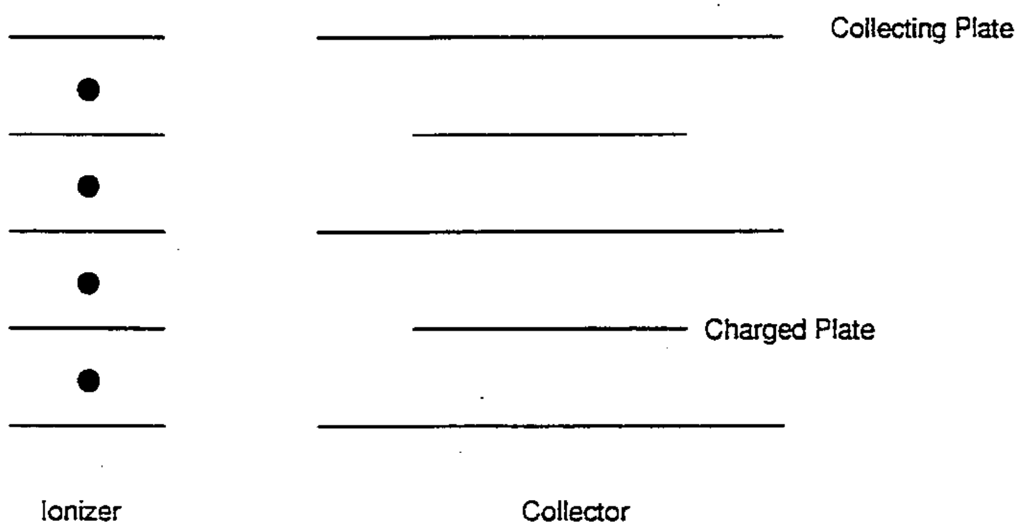


Figure 301.2 Charging and Collection Process for Two-Stage ESPs[20]

300 THEORY AND DESIGN

Particle Charging

In both types of precipitators, particle charging consists of the following:

1 "Corona" generation around the discharge electrode, resulting in ionization of the flue gas molecules surrounding the particles;

2 Impaction of particles by gas ions, by means of "field" and "diffusion" mechanisms, resulting in the transfer of charge to the particles.

Single Stage Precipitators

Single-stage precipitators use negatively charged discharge electrodes, while two-stage precipitators use positively charged discharge electrodes. The particles, when charged, take on the same polarity as the discharge electrode.

The charged particles are attracted to the oppositely charged or grounded collection electrodes. They precipitate out of the gas stream and become attached to the collection electrodes.

The following paragraphs describe in greater detail the particle charging process in a single-stage precipitator.

An electric field is generated by applying a potential difference across two terminals. The voltage applied to the discharge electrode, when large enough, forms a corona, which appears as a luminous blue glow. The corona is a flue gas phenomenon in which the flue gas molecules are ionized by electron collisions in this area of high electric field. The strong electric field close to the discharge electrode accelerates the free electrons that are present in the gas. These electrons acquire sufficient velocity to ionize gas molecules upon collision, producing a positive ion and an additional free electron.

The additional free electrons create more positive ions and free electrons as they collide with additional gas molecules in a process called avalanche multiplication. This process occurs in the corona glow region, and continues outward from the discharge electrode until the electric field has insufficient energy to perpetuate ionization. The electrons proceed to the positive electrode, while the positively charged ions migrate to the discharge electrode. If the positive ions encounter particles moving close to the discharge electrode, they will attach to the particles. This results in particle deposition on the discharge electrodes. Figure 301.3 represents the basic processes involved in electrostatic precipitation.

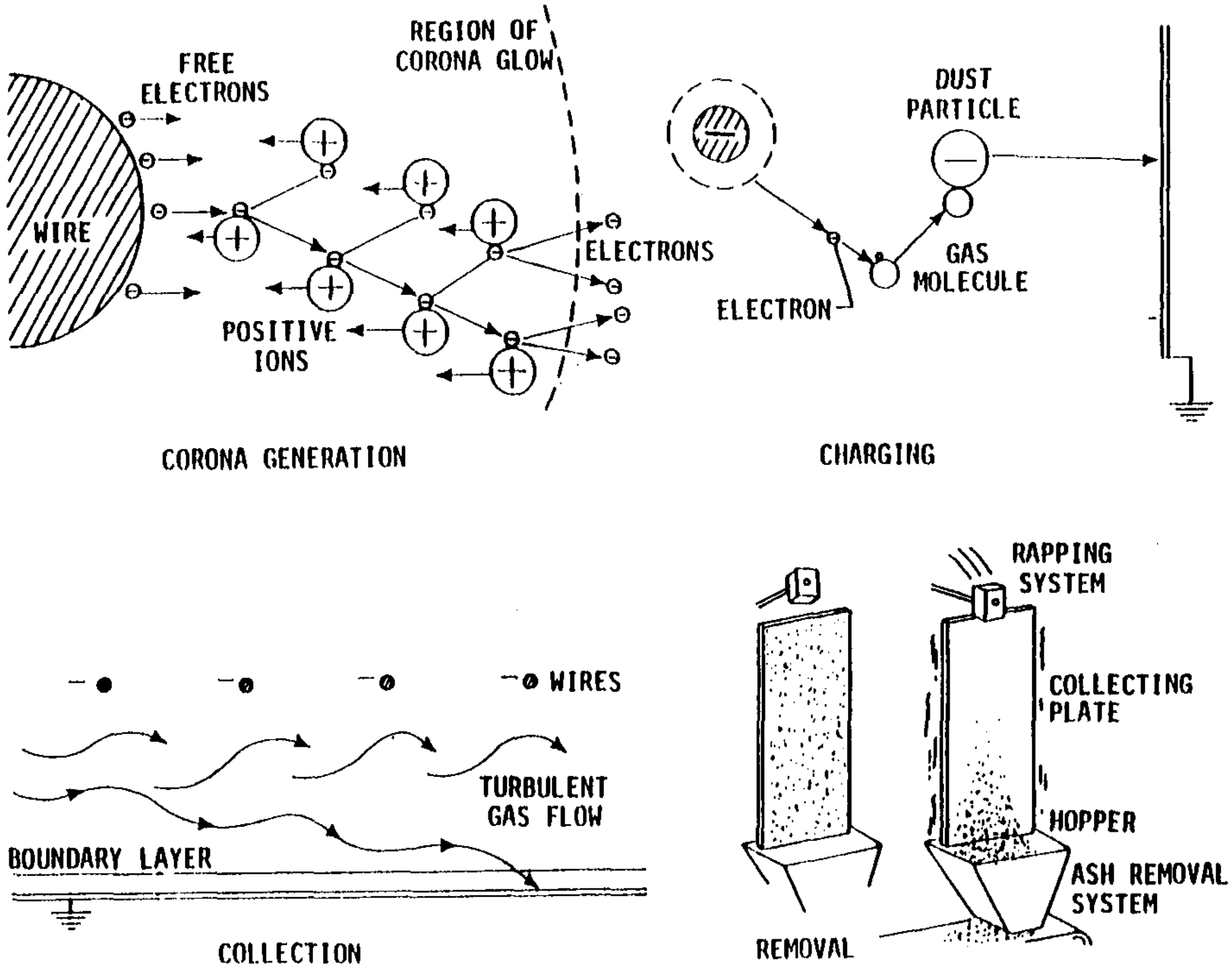


Figure 301.3 Basic Processes Involved in Electrostatic Precipitation [1]

The electrons leaving the corona area enter the inter-electrode area. Here they are captured by gas molecules. Upon impact with them, negative gas ions are formed. These ions serve as the principal mechanism for charging of the particulate matter.

The negative gas ions charge particulate matter in two ways: field charging and diffusion charging. Field charging is the dominant mechanism in the case of particles larger than 0.5 micron in diameter, while diffusion charging is more effective in the case of particles under 0.2 micron diameter. A combination of the two mechanisms is operative in the case of particles between 0.1 and 1 micron. Particles in the range of 0.2 micron to 0.4 micron are the most diffucult to charge, and are thus the most difficult to collect. ESP efficiency suffers when particles of this size occur in large numbers in inlet conditions.

Field Charging

In the case of field charging, particles crossing electric field lines are bombarded by negative gas ions as these flow along the field lines. The ions attach to the particles. The number of ions possible on the surface of a particle is proportional to the square of the particle diameter. (It is for this reason that the efficiency of an ESP is particle size dependent.) This process continues until the electric field lines diverge around the negatively charged particle, which is then said to be saturated. These particles migrate to the grounded electrode, where they are collected. The time required for a particle to reach its saturation charge varies inversely with the ion density in the region where charging is taking place. Under normal conditions with sustained high-current levels, charging times are only a few milliseconds. Limitation of current because of high resistivity or other factors can lengthen the charging times significantly and cause the particles to travel several feet through the precipitator before saturation charge is approached.

Diffusion Charging

Diffusion charging occurs when randomly moving negative ions collide with particles. This kind of charging is related to the random Brownian motion of negative gas ions, which causes the ions to diffuse through the gas and contact particles. As with field charging, diffusion charging is influenced by the magnitude of the electric field, since ion movement is governed by electrical as well as diffusional forces. The charging rate decreases as a particle acquires a charge and repels additional gas ions, but charging continues to a certain extent because there is no theoretical saturation or limiting charge other than the limit imposed by the field emission of electrons. This is because the distribution of thermal energy ions will always overcome the repulsion of the dust particle.

302 PARTICLE COLLECTION THEORY

Methods in current use for sizing electrostatic precipitators include design by analogy to similar installations and by theoretical application of fundamental precipitation principles. Design by analogy is most reliable for industrial process ESP installations where few process variabilities influence the collection conditions.

Deutsch-Anderson Model

The first equation for predicting particle collection probability was developed by Anderson in 1919. It was derived again by Deutsch, who used a different method, in 1922. In various forms, this equation, $n = 1 - e^{-(aw/v)}$, has become the basis for estimating precipitator efficiency on the basis of gas flow, precipitator size, and precipitation rate parameter. In this equation, n is the precipitator collection efficiency, a is the total collecting electrode surface area, v is the gas flow rate, and w is the migration velocity of the particles. When determined empirically, the precipitation rate parameter, w, includes effects of rapping losses, gas flow distribution, and particle size distribution.

The Deutsch-Anderson model assumes that particulate concentration is uniform in any cross section perpendicular to the gas flow of an ESP. This assumption is made because of the turbulence of the gas, which takes the particles near the collection surface and allows them to become electrically charged. A serious limitation in use of the Deutsch-Anderson equation is that it does not account for changes in the particle size distribution and subsequently the effective migration velocity as precipitation proceeds. This limitation affects the accuracy of sizing estimates for units operating at very high efficiencies (approximately 98% and above) because of the change in w with particle size.

In practice, factors such as particle reentrainment and gas leakage cannot be accounted for theoretically. In addition, some of the most important physical and chemical properties of the particles and gases often are not known. Therefore, most designers use an effective precipitation rate parameter, w_e, that is based mainly on field experience rather than theory. Data from operating installations form a general basis for selection of w_e, and these data are modified to fit the particular situation being evaluated. Thus w_e becomes a semiempirical parameter that can be used in the Deutsch-Anderson equation or its derivatives to estimate the collection area required for a given efficiency and gas flow. The most important parameters that determine w_e in practice are resistivity, particle size distribution, gas velocity distribution through the ESP, particle loss due to reentrainment, rapping and gas leakage, ESP electrical conditions, and required efficiency.

Matts and Ohnfeldt

A semiempirical modification of the Deutsch-Anderson equation that essentially removes the size dependency from w was developed by Matts and Ohnfeldt. This equation is $n = 1 - e^{-w_k(A/V)^k}$. In most cases, k equals approximately 0.5. The modified migration velocity, w_k, can be treated as being independent of charging voltage and current levels and of particle size distribution within an ESP, as precipitation proceeds in the direction of gas flow. Other changes, however, such as in properties of the gas entering the ESP, resistivity, and size distribution, produce a change in w_k just as they change the conventional w.

303 ESP DESIGN TYPES

Electrostatic precipitators can be classified in two main categories: high voltage, single-stage and lower voltage, two-stage precipitators. These two types differ as to the charging mechanism used. The single-stage precipitator is the better known type, and has been used successfully to collect both solid and liquid particulate matter in industrial facilities such as smelters, steel furnaces, cement kilns, municipal incinerators, and utility boilers. Two-stage precipitators are used mainly for air cleaning in heating, ventilating and air conditioning systems. Additional applications are in the collection of liquid aerosols discharged from sources such as meat smokehouses, pipe coating machines, asphalt paper saturators, high speed grinding machines, charbroiling restaurants, textile tenter frames, and vinyl fabric coating operations.

303.1 TWO STAGE ESPS

Low Voltage ESPs

Low voltage, two-stage ESPs were originally designed for air purification in conjunction with air conditioning systems (they are also referred to as electrostatic air filters). Two-stage ESPs have been used primarily for the control of finely divided liquid particles. Controlling solid or sticky materials is usually difficult, and the collector becomes ineffective for dust loadings greater than 0.4 grains per standard cubic foot (7.35×10^{-4} g/m^3). Therefore, two-stage precipitators have limited use for particulate emission control.

The low voltage two-stage precipitator differs from the high voltage single-stage precipitator in terms of both design and the amount of applied voltage. The two-stage ESP has separate particle charging and collection stages, as can be seen in figure 303.1. The particle charging (or ionizing) stage consists of a series of small (0.007 inch diameter) positively charged wires equally spaced 1 to 2 inches from parallel grounded tubes or rods. A corona discharge between each wire and a corresponding tube charges the particles suspended in the air flow through the ionizer. The direct current (DC) potential applied to the wires is approximately 12 to 15 kV.

The second stage consists of parallel metal plates about a fourth of an inch apart. Every other plate is given a negative charge, so that a potential difference of 6 to 7 kV exists between adjacent plates. Positively charged liquid particles flowing between these plates are repelled by the positively charged plates, and

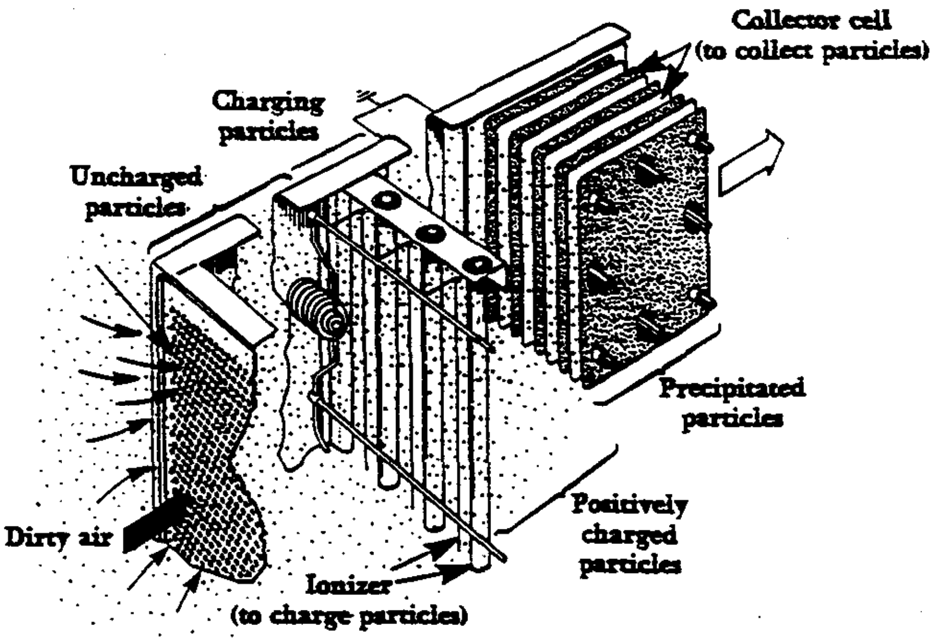


Figure 303.1 Typical Two-Stage ESP [2]

collect on the grounded plates. Collected liquids drain by gravity to a pan located below the plates.

Two-stage precipitators are well suited to the relatively low mass concentration rates of particulate matter experienced in the applications named earlier. These precipitators are often arrayed in series, so that the unit has a number of fields. This enables the attainment of practically any collection efficiency.

303.2 SINGLE-STAGE PRECIPITATORS

Single-stage precipitators may be divided into two main groups: wet and dry ESPs. Within each of these categories, precipitators can be further classified by electrode geometry, and by location in a process. The difference in the latter case has to do with operating temperatures in dry ESPs. Sections 303.2.1 through 303.2.2 further describe these different design types.

303.2.1 Dry Precipitators

Dry precipitators are so named to contrast them with wet precipitators, which are described in section 303.2.2. Dry precipitators are much more common in industrial applications. This manual deals with dry precipitators for the most part.

Dry precipitators are installed in industries with widely varying conditions of gas temperature and pressure, such as cement kilns, metallurgical furnaces, and electric utility power boilers. In the electric utility industry, precipitators are classified as hot or cold, depending on the location of the ESP relative to the air preheater. Figure 303.2 shows a typical dry ESP.

Hot-Side and Cold-Side ESPs

The typical cold-side ESP is located downstream of the air preheater (a heat exchanger), and operates in the range of 100 °F to 200 °F. The greatest disadvantage with cold-side precipitators is that their efficiency varies with fuel composition and boiler firing conditions. The efficiency of a hot-side unit is less dependent on these factors.

Hot-side ESPs are located upstream of the boiler air preheater. The operating temperature is generally between 600 °F and 800 °F. At this temperature, the resistivity of fly ash is significantly lessened. Also, because of the ESPs location, the heat transfer surfaces of the air preheater are less likely to be fouled by fly ash. There are corresponding reductions in the need for soot blowing of the air preheater and in hopper plugging. One drawback of locating the ESP upstream of the air preheaters is that the soot blown from the air preheater cannot be captured; this may result in occasional increased emissions.

The typical hot-side ESP operates at lower voltages than a cold-side unit. If designed correctly, it operates at much higher current densities and is characterized by a relatively high power density and by stable, current-limited operation.

Thermal Expansion

Thermal expansion has been a problem with hot ESPs. After construction at ambient temperatures, the internals are maintained during operation at approximately 650 °F to 750 °F, while the externals remain near ambient temperatures. Adequate provision for differential movement of the precipitator on its support structure, proper insulation, and adherence to design stress values have largely eliminated this problem.

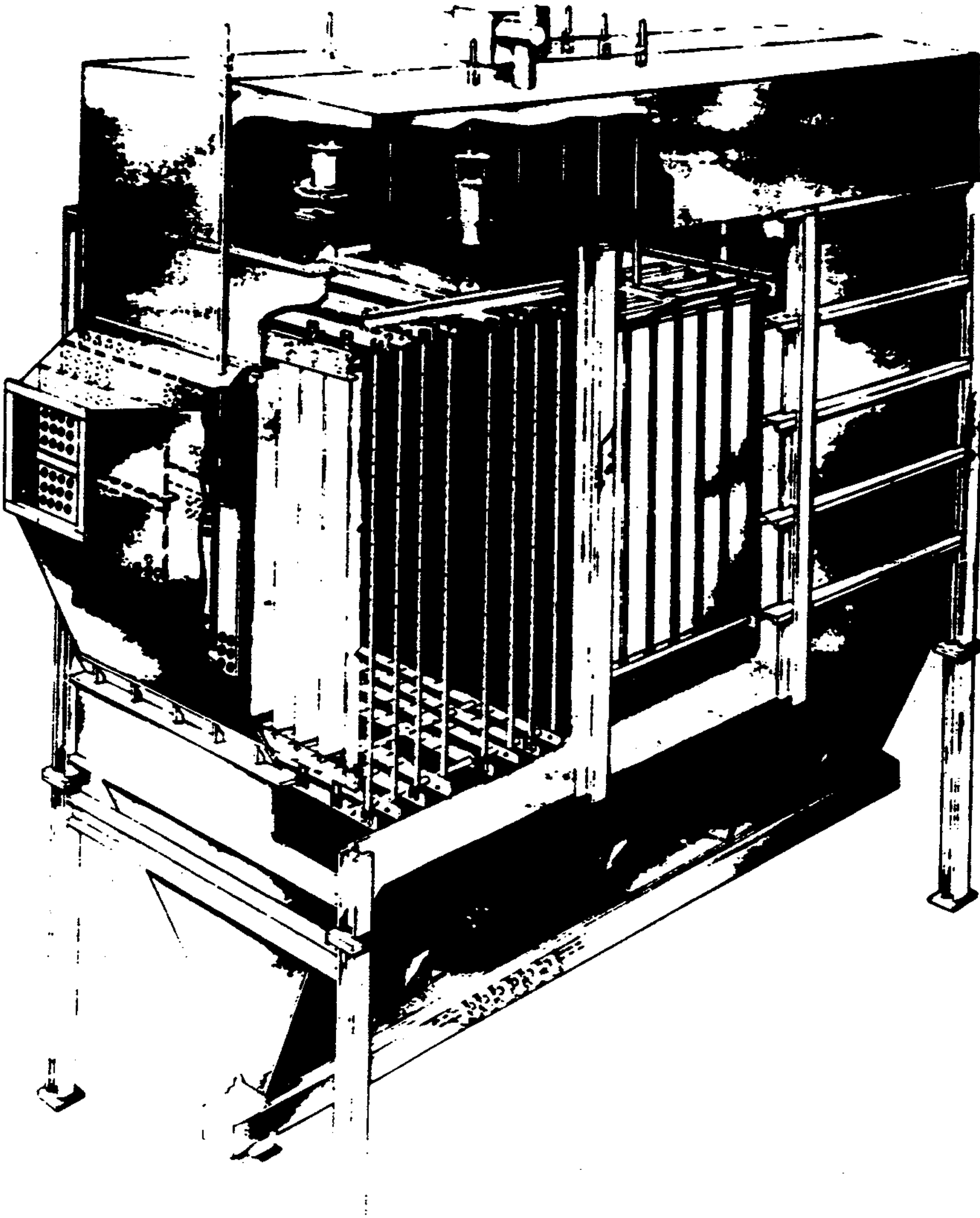


Figure 303.2 Typical Rigid Electrode ESP [3]

Some ESP manufacturers favor cold-side installations, others stress hot-side units; there is no adequate rule of thumb for choice of either type. The selection is usually based on operability, economics, and particulate characteristics.

303.2.2 Wet Precipitators

Wet precipitators are used primarily in the metallurgical industry, usually operating below 170 °F (75 °C). Until the late 1960's, their use was restricted mostly to acid mist, coke oven off-gas, blast furnace, and detarring applications. Their use in other areas is rapidly increasing as air pollution control codes for those areas are becoming more stringent. The newer applications include sources with sticky and corrosive emissions that must meet these standards. Because of inherent temperature range limitations, they are not used for boiler installations.

The fundamental difference between a wet and a dry ESP is that a thin film of liquid flows over the collection plates of a wet ESP to wash off the collected particulates. In some cases, the liquid is also sprayed in the gas flow passages to provide cooling, conditioning, or sometimes a scrubbing action. When the liquid spray is used, it is precipitated with the particles, providing a secondary means of wetting the plates. Three different wet ESP configurations are discussed below.

Plate Type (Horizontal Flow)

The effluent gas stream is usually preconditioned to reduce temperature and achieve saturation. Figure 303.3 illustrates this type of ESP. As the gas enters the inlet nozzle, its velocity decreases because of the diverging cross section. At this point, additional sprays may be used to create good mixing of water, dust, and gas as well as to ensure complete saturation before the gas enters the electrostatic field. Baffles are often used to achieve good velocity distribution across the inlet of the precipitator.

Within the charging section, water is sprayed near the top of the plates in the form of finely divided drops, which become electrically charged and are attracted to the plates, coating them evenly. Simultaneously, solid particles are charged; they "migrate" and become attached to the plates. Since the water film is moving downward by gravity on both the collecting and discharge electrodes, the particles are captured in the water film, which is disposed of from the bottom of the precipitator in the form of slurry.

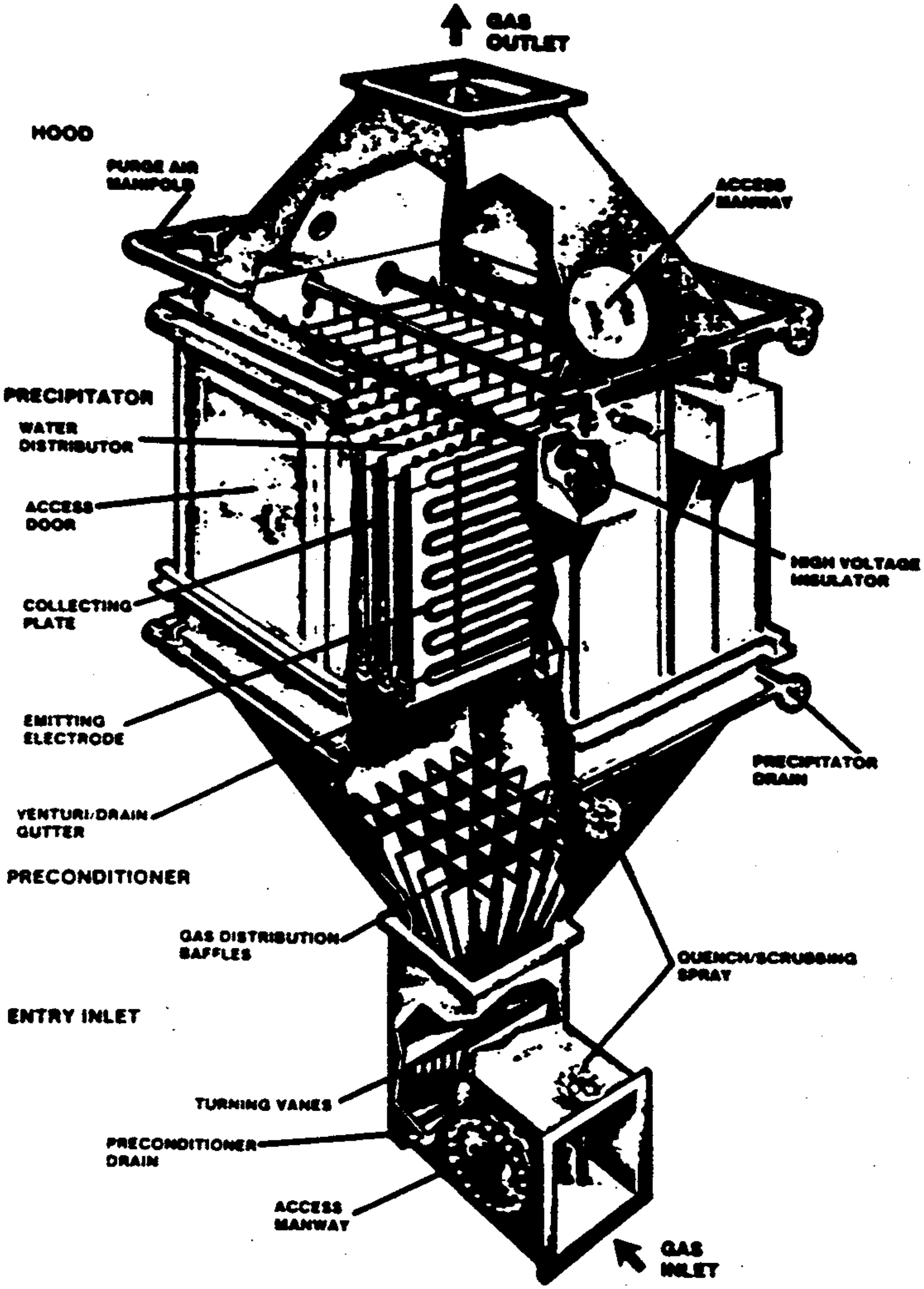


Figure 303.3 Flat Plate Type Wet ESP [3]

300 THEORY AND DESIGN

Concentric Plate ESP

The concentric-plate ESP consists of an integral tangential prescrubbing inlet chamber followed by a vertical wetted-wall concentric-ring ESP chamber. This configuration is illustrated in figure 303.4. Concentric cylindrical collection electrodes are wetted by fluids dispensed at the top surface of the collection electrode system. The discharge electrode system is made of expanded metal with uniformly distributed corona points on the mesh background. This system is intended to combine the high, nearly uniform, electric field associated with a parallel plate system and the nearly uniform distribution of corona current density associated with closely spaced corona points. Higher gas flow can be handled by adding concentric electrode systems and by increasing the length of each electrode.

Conventional Pipe-Type ESP

This system, as shown in figure 303.5, consists of vertical collecting pipes, each containing a discharge electrode (wire type), which is attached to the upper framework and held taut by a cast-iron weight at the bottom. A lower steadying frame keeps the weights and thus the wires in position.

The upper frame is suspended from the high-voltage insulators housed in the insulator compartments, which are located on top of the precipitator shell (casing). Heating and ventilating systems help to prevent accumulation of moisture and dust in the insulator compartments.

The washing system usually consists of internal nozzles located at the top of the plates. At specified intervals, the tubes are washed thoroughly. During the washing, the louver damper to the exhaust fan is closed to prevent carryover of droplets.

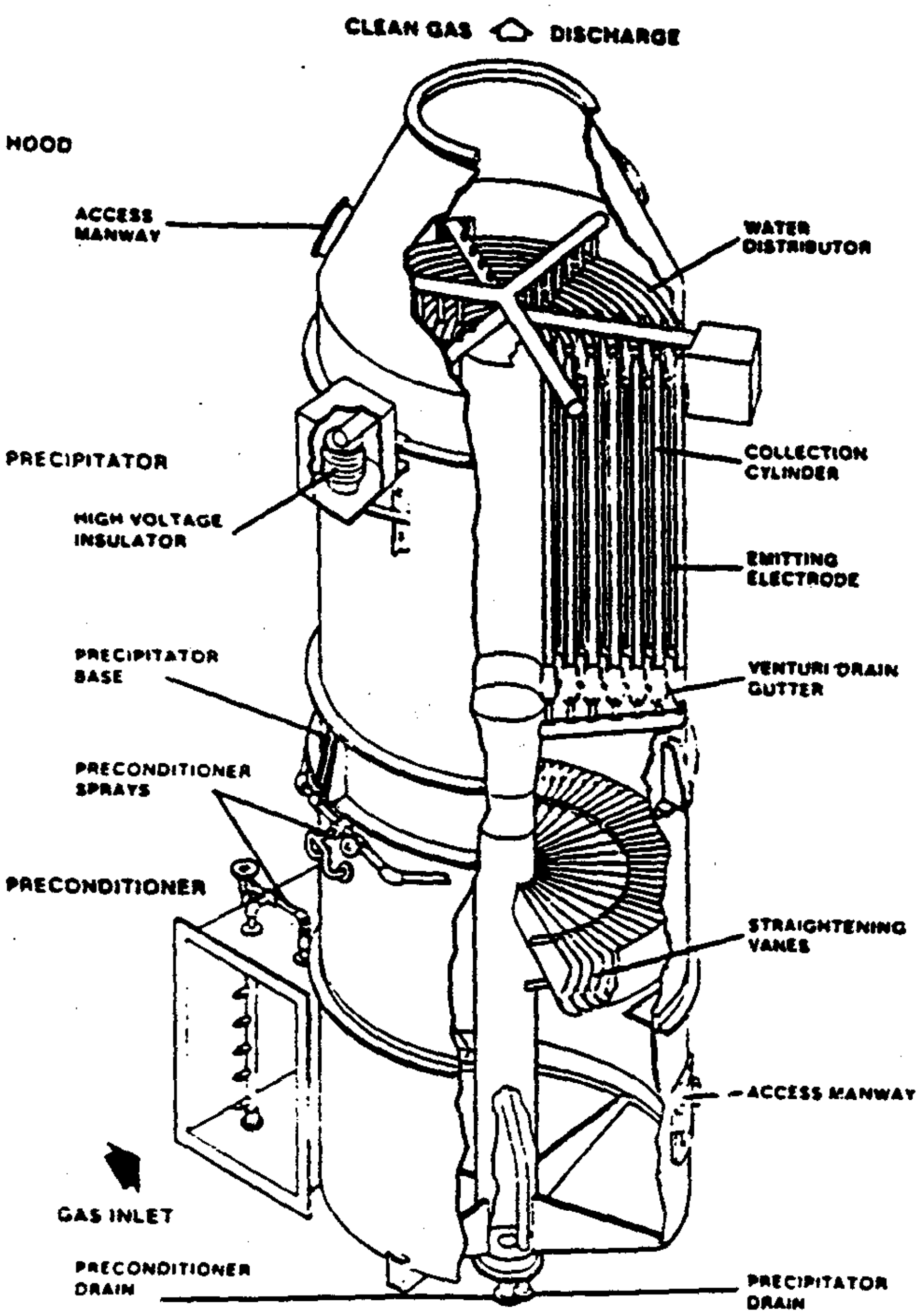


Figure 303.4 Concentric Plate Wet ESP [3]

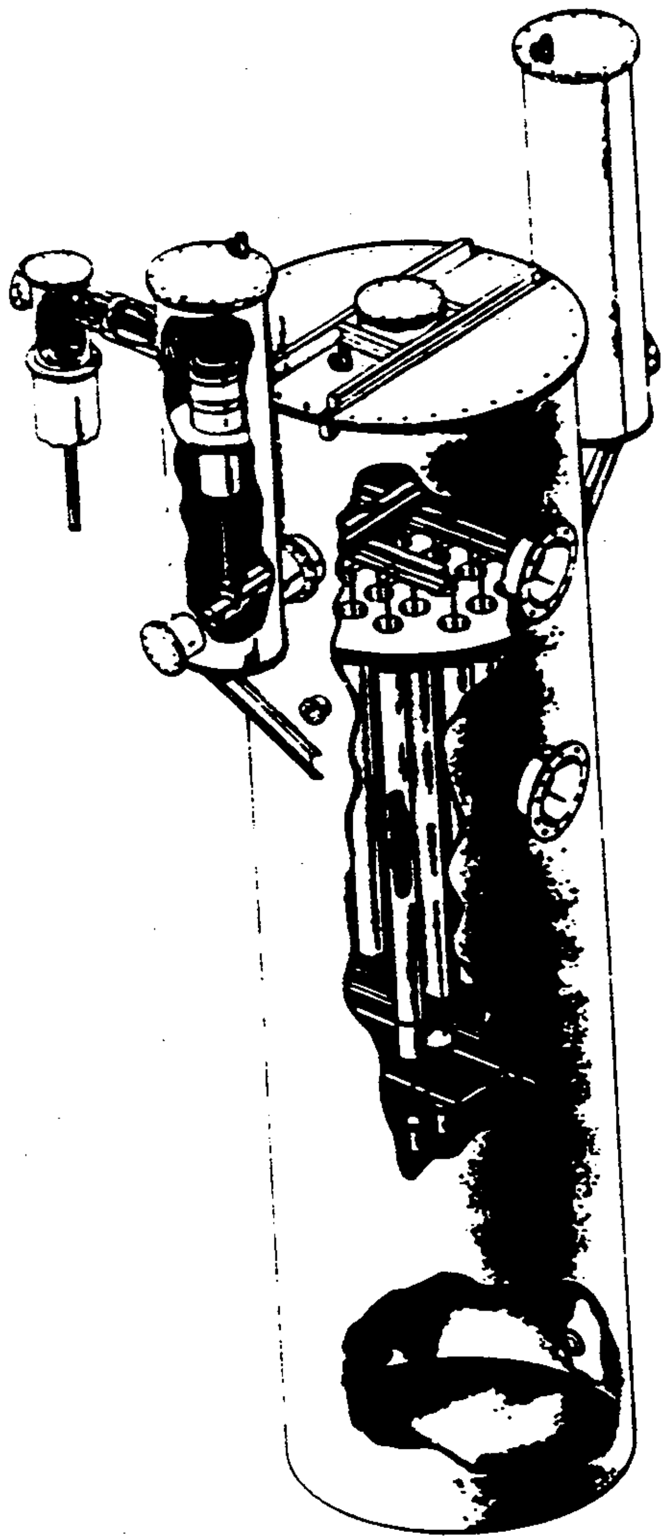


Figure 303.5 Circular Plate Wet ESP [3]

304 ESP APPLICATIONS

Dry ESPs are used in all basic industries and also in some specialized applications. The electric utility industry is the biggest user of ESPs nationwide, but other large users include the cement industry (rotary kilns), the pulp and paper industry (kraft recovery boilers), municipal incinerators, ferrous metallurgical applications (copper, lead, zinc, and aluminum smelting), the petroleum industry (fluid catalytic crackers, detarring), the chemical industry (sulfuric acid plants), and industrial boilers of all types. The particulate matter from these sources can can generally acquire an electrical charge quite readily, and an ESP can be designed to treat large gas volumes at high temperatures (up to 2000 °F) and several atmospheres of pressure.

Table 304.1 presents operating conditions for ESPs in major application areas. These data show the wide range of temperature, pressure, and particulate concentration under which an ESP can operate.

Wet ESPs are generally used for applications where the potential for explosion is high, where particulate is very sticky, and for high resistivity applications. Where moisture or chemical substances are needed to increase the conductivity of the particulate, dry ESPs can be equipped with a conditioning system.

A wet ESP can be used alone or in conjunction with wet scrubbers, which remove both particulate and gaseous pollutants (such as fluorides). Wet ESPs are used to control a variety of industrial processes, including :

1 Sulfuric acid mist;

2 Coke oven gas, blast furnaces, detarring and basic oxygen furnaces, scarfers and cupolas in the iron and steel industry;

3 Aluminum potlines.

The conditioning of the incoming gas stream and continual washing of the internal components with water eliminate resistivity and reentrainment problems. Some gaseous pollutant removal can also occur, but such removal is limited by the solubility of the gaseous component in the wash liquor. Organics that condense are also collected in a wet ESP. Significant collection of submicron particles is also possible in a wet ESP.

Table 304.1
Operating Conditions of ESPs [4]

Application area	Temperature °F	Pressure psia	Concentration gr/scf	Efficiency %
Electric utility	225 - 900	14.7	1.5 - 7.5	90 - 99.6
Pulp and paper	225 - 375	14.7	1.0 - 9.0	90 - 99.5
Iron and steel	70 - 600	14.7	0.01 - 3.0	85 - 99.8
Rock products	350 - 700	14.7	3.7 - 156	92 - 99.9
Chemical processes	80 - 800	14.7	0.2 - 50	85 - 99.9
Nonferrous metals	70 - 1100	14.7	0.01 - 45	90 - 99.9
Petroleum	70 - 850	7.5 - 164	0.8 - 40	80 - 99.7
Refuse combustion	450 - 550	14.7	0.5 - 4.0	95 - 99.2
Miscellaneous	90 - 1700	65 - 825	10^{-5} - 3.0	95 - 99.5

305 DESIGN FACTORS AFFECTING PERFORMANCE

Table 303.1 summarizes ranges of values for important basic design parameters that are discussed in this section. The three most important parameters that affect the size of an ESP are collection area, gas velocity, and aspect ratio. These and other parameters are discussed in sections 303.1 through 303.8.

305.1 FLUE GAS VOLUME FLOW

The volume flowrate of flue gas from any process must be determined to accurately size a precipitator.

ACF

SCF

Flue gas volume units can be expressed in Actual Cubic Feet (ACF), or Standard Cubic Feet (SCF). Air quality control equipment design normally considers ACF. Actual cubic feet volume is the gas volume at the actual temperature and pressure of the gas. Standard cubic feet volume refers to a standard condition for temperature and pressure. Standard temperature and pressure are usually 60 °F and 14.7 psia. However, standard temperature may be 32 °F, 68 °F or 80 °F, and should always be defined when using SCF notation.

The perfect gas law should be used to correct gas volumes. To express an SCF measurement in terms of ACF, the following equation should be used:

$$ACF = 14.7/PA \times [(460 + TA)/520] \times SCF$$

where:

PA = Actual pressure in psia

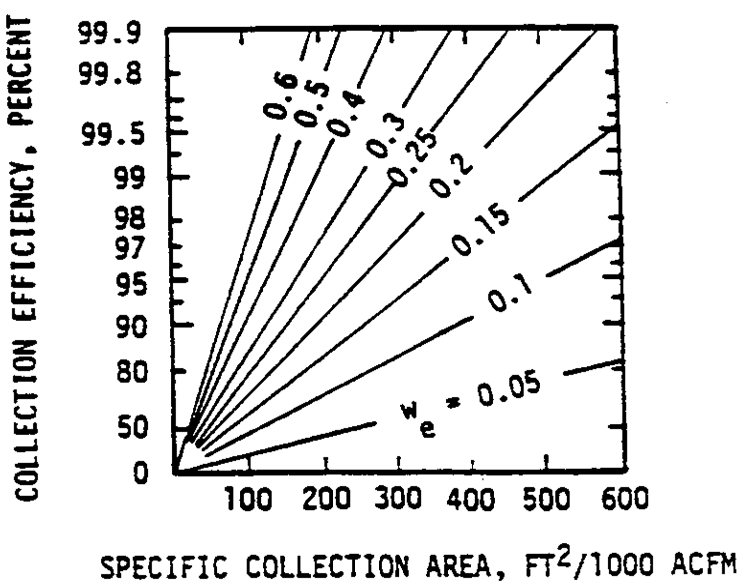
TA = Actual temperature in °F

SCF = Standard cubic feet volume (at 14.7 psia and 60 °F)

Gas volume is also affected by air leakage in the process and air heater. This additional gas volume must be processed by the ESP. Changing the gas flowrate from design conditions will have a corresponding affect on the velocity of the gas through the precipitator and the inlet grain loading. These will affect the precipitator's performance.

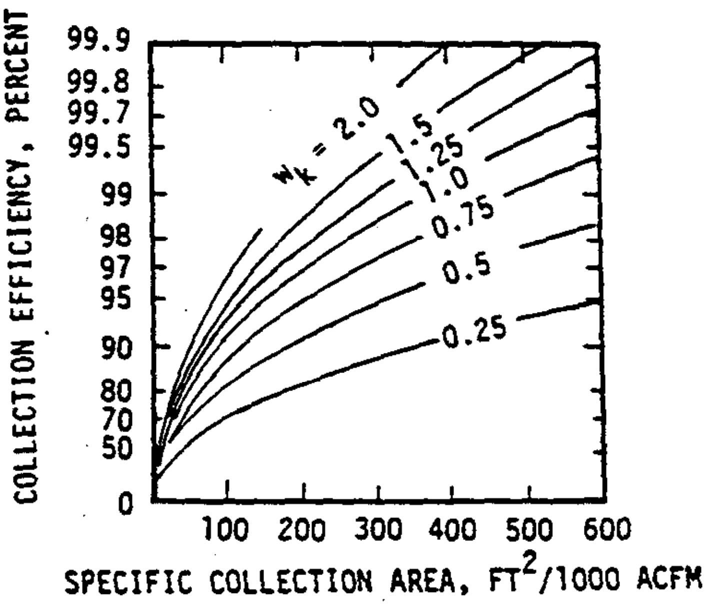
305.2 SPECIFIC COLLECTION AREA

Some variation of the Deutsch-Anderson equation is generally used to estimate the required collection plate area. Figures 305.1 and 305.2 present the relationships of specific collecting areas (SCA) developed with the Deutsch-Anderson w_e and Matts Ohnfeldt w_k, respectively.



METRIC CONVERSION: FT^2/1000 ACFM x .055 = m^2/1000 m^3/ sec

Figure 305.1 ESP Efficiency vs. SCA and w_e [5]



METRIC CONVERSION: $FT^2/1000$ ACFM x .055 = $m^2/1000\ m^3/sec$

Figure 305.2 ESP Efficiency as a Parameter of SCA and w_k [5]

305.3 MAXIMUM SUPERFICIAL VELOCITY

Designers calculate an average (superficial) value for gas velocity from gas flow and cross sectional area of the precipitator, independent of the localized variances within the precipitator. The primary importance of the superficial gas velocity is to indicate the average velocity level and to subsequently calculate the average residence time. Above some critical velocity (6.5 ft/sec or 2 m/sec) rapping and reentrainment losses tend to increase rapidly because of the aerodynamic forces on the particles. This critical velocity is a function of gas flow, plate configuration, precipitator size, and other factors such as resistivity. Values for gas velocity in fly ash precipitators range from 3.0 ft/sec to 4.0 ft/s (0.9 to 1.2 m/sec) in high-resistivity, cold-side ESP applications, and in all low-resistivity applications (hot or cold side). For most other applications, the values range from 3.0 ft/sec to 5.5 ft/s (0.9 to 1.7 m/sec).

305.4 ASPECT RATIO

Aspect ratio is defined as the ratio of the length to the height of gas passage. In effect, it defines the time allotted for the particles to fall into the hoppers (as does the superficial velocity). The higher the aspect ratio, the higher will be the efficiency of the precipitator.

Although space limitations often determine precipitator dimensions, the aspect ratio should be high enough so that the reentrained dust carried forward from inlet and middle sections can be collected. In practice, aspect ratios range from 0.6 to 1.5. For efficiencies of 99 percent or higher, the aspect ratio should be at least 1.0 to 1.5 to minimize carry-over of collected dust.

305.5 COLLECTING PLATE SPACING

Collecting plate spacing is the distance between the centers of adjacent collecting plates which form a gas passage. As the width of the gas passages increases, higher voltages must be applied to the discharge electrode to maintain the efficiency at which the particulate is being charged. The spacing between negatively charged and grounded electrodes must be sufficiently great that sparkover does not occur at a corona voltage that is too low to charge the particulate at the same efficiency. The designed collection plate spacing is therefore a carefully chosen dimension. It becomes easy to understand why misalignment of plates causes the ESP's efficiency to suffer.

Precipitators using wire-weighted discharge electrodes usually have a collection plate spacing of 9 inches, while ESPs with rigid-frame discharge electrodes typically have a spacing of 10 to 12 inches. Plate spacing for the rigid-frame discharge electrodes must be increased to compensate for the physical thickness and tolerance of the rigid frame assembly.

305.6 CHAMBER, BUS, FIELD AND CELL CONFIGURATIONS

Chamber

A chamber is a gas-tight longitudinal subdivision of a precipitator. An ESP without any internal dividing wall is a single chamber precipitator.

Bus Section

A bus section is the smallest portion of a precipitator that can be independently energized.

Field

A field is the physical portion of the precipitator in the direction perpendicular to gas flow (lateral) that is energized by a single power supply. The greater the number of fields or stages in an ESP, the greater the overall collection efficiency of the unit.

Cell

A cell is a longitudinal row of bus sections extending from the front to the rear of an ESP. Therefore, one would expect a wider ESP to have more cells than a narrower unit.

Sectionalization of ESPs

Sectionalization of an ESP is accomplished by subdividing the high-voltage system and arranging the support insulators. Some power system arrangements are shown in Figure 305.3.

The sectionalization of precipitators is very important. First, if the precipitator is sparking (as described in section 305.9), less of the precipitator is disabled during the spark interval if the system is highly sectionalized. Higher average voltage and higher electric field levels are maintained, and precipitator efficiency is not reduced. Also, the smaller electrical sets have higher internal impedances, which facilitate spark quenching and minimize the tendency of a spark to arc. Smaller precipitator sections localize the effects of electrode misalignment and permit higher voltages in the remaining sections. Finally, with adequate sectionalization in very large precipitators, reasonably good collection efficiencies can be maintained if a section must be deenergized because of wire breakage or other electrical trouble. All new ESPs are designed so that if one field shorts out, the overall ESP efficiency will not fall below specifications.

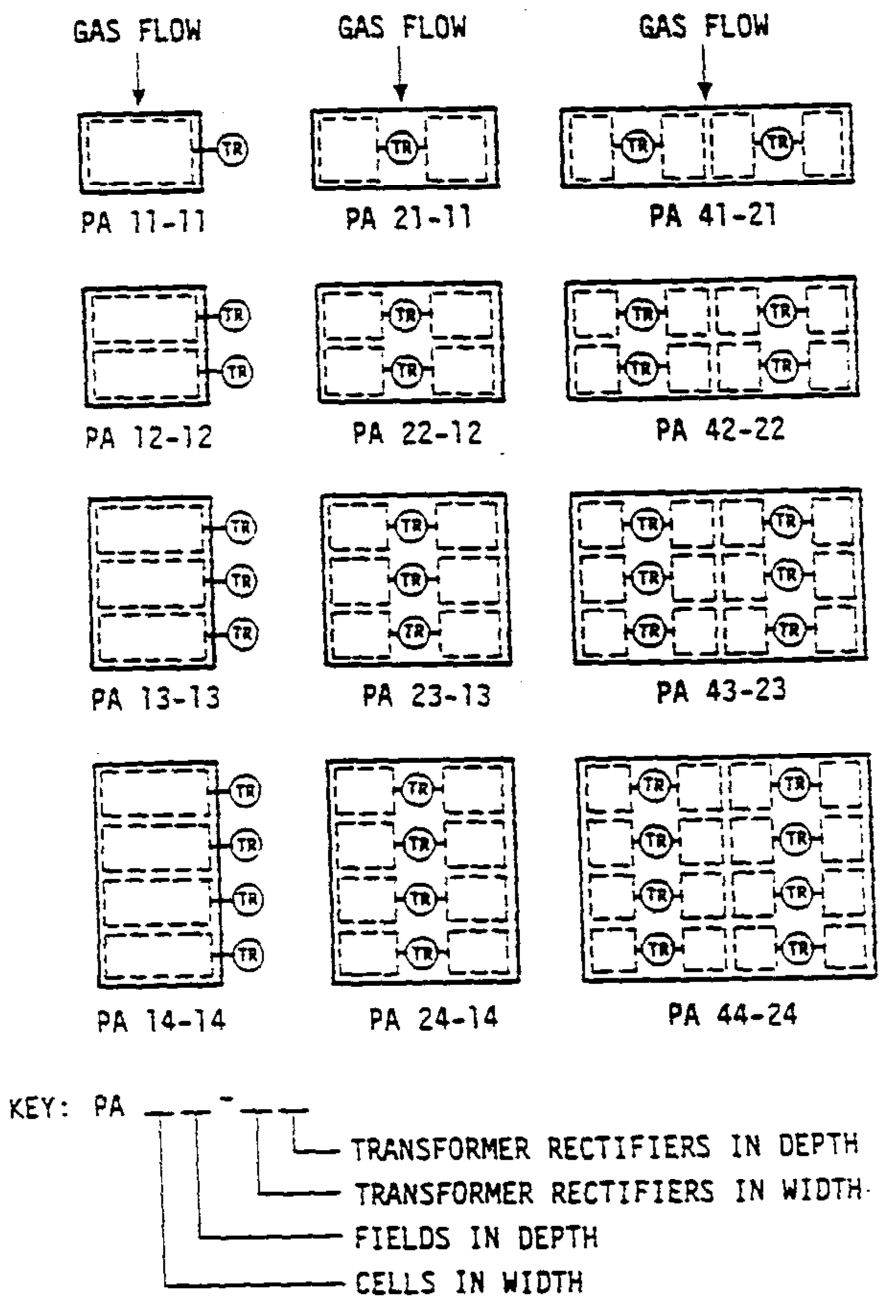


Figure 305.3 Various Combinations of Electrical Sectionalization in an ESP [6]

305.7 DUST RESISTIVITY

Since dust resistivity can greatly limit precipitator performance when it is outside the preferred range of 10^8 ohm-cm to 10^{10} ohm-cm, it is a major factor in precipitator technology. Resistivity plays a major role in the electrical conditions of the collection dust layer, influencing the:

1 electric field stress in the dust layer

2 voltage drop across the dust layer, and

3 electrical force component holding the dust layer to the collection plate.

Resistivity also affects the electrical operating conditions of an ESP, due to 1) its impact on particle charging, and 2) the interdependent relationship between dust layer conditions and the operating voltage and current levels.

Table 305.1 provides a brief description of characteristics associated with the typical levels of dust resistivity. The identified characteristics reflect generalized cases and conditions, indicating that an optimum range exists for resistivities between 10^8 and 10^{10} ohm-cm. As resistivity levels deviate from the preferred range, special design considerations need to be made to compensate for the respective change in precipitation characteristics. Accordingly, for ESPs treating streams with fluctuating resistivity levels, (e.g., different temperature, moisture, fuel quality), special or different ESP operation may be necessary to maintain collection performance.

Fly Ash Resistivity

Fly ash resistivity depends primarily on the chemical composition of the ash, the ambient flue gas temperature, and the amounts of water vapor and SO_3 in the flue gas. High resistivity, which is characteristic of certain low-sulfur coals, causes uncertainly in sizing cold-side ESPs, which generally operate at temperatures of 250 °F to 350 °F (120 °C to 175 °C).

At low temperatures [<175 °F (<80 °C)], current conduction occurs principally along the surface layer of the dust and is related to the absorption of water vapor and other conditioning agents in the flue gas. For fly ash, resistivity is primarily related in an inverse manner to the amount of SO_3 and moisture in the flue gas.

At elevated temperatures [<400 °F (<200 °C)], conduction takes place primarily through the bulk of the material, and resistivity depends on the chemical compo-

Table 305.1
ESP Characteristics Associated With Different Levels of Resistivity [2]

Resistivity level ohm-cm	ESP Characteristics
$< 10^8$	(1) Normal operating voltage and current levels. (2) Reduced electrical force component retaining collected dust, vulnerable to high reentrainment losses. (3) Negligible voltage drop across dust layer. (4) Reduced collection performance, due to (2).
10^8 to 10^{10}	(1) Normal operating voltage and current levels. (2) Negligible voltage drop across dust layer. (3) Sufficient electrical force component retaining collected dust. (4) High collection performance, due to (1), (2), and (3).
10^{11}	(1) Reduced operating voltage and current levels with high spark rates. (2) Significant voltage loss across dust layer. (3) Moderate electrical force component retaining collected dust. (4) Reduced collection performance, due to (1), (2).
$>10^{12}$	(1) Reduced operating voltage levels; high operating current levels. (2) Very significant voltage loss across dust layer. (3) High electrical force component retaining collected dust. (4) Seriously reduced collection performance, due to (1), (2), and probable back corona.

Typical values

Operating voltage:	30 - 70 kV, dependent on design factors
Operating current density:	5 - 50 mA/cm^2
Dust layer thickness:	0.5 - 2 cm (1/4 - 1 in.)

sition of the material. For fly ash, resistivity above 400 °F (200 °C) is generally below the critical value of about 10^{10} ohm-cm, although it has been shown to decrease with increasing amounts of sodium, lithium, and iron.

The range of operation of cold-side fly ash precipitators is 250 °F to 400°F (120 °C to 200 °C), a range in which conduction takes place by a combination of the surface and bulk mechanisms and resistivity of the ash is highest. Figure 305.4 illustrates the relationship between resistivity, temperature, and responsible conduction mechanisms.

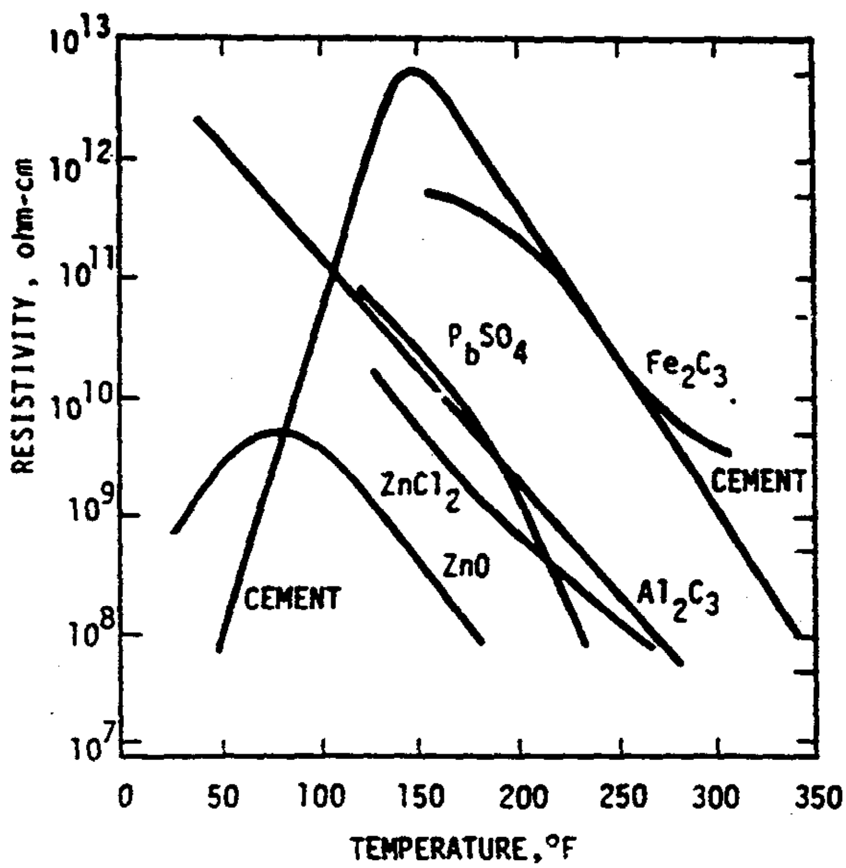


Figure 305.4 Resistivity of Several Dusts at Various Temperatures [8]

305.8 PARTICLE SIZE DISTRIBUTION

The greater the size of a particle, the more easily an ESP will collect it. Particles in the 0.2 micron to 0.4 micron diameter range are the most difficult to collect because in this size range, the fundamental field charging mechanism gives way to diffusion charging by random collision as a charging mechanism for very small particles. This process is outlined in section 301. Figure 305.5 shows a typical relationship between ESP efficiency and particle size.

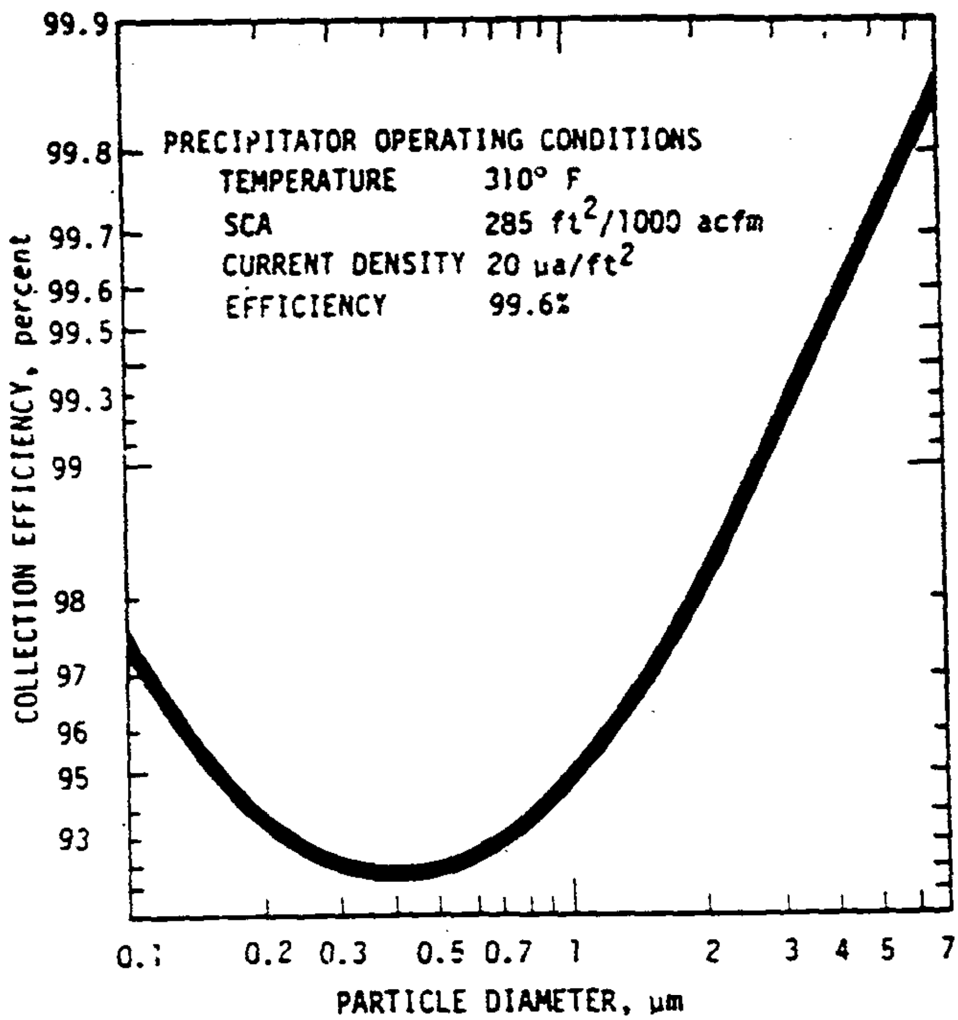


Figure 305.5 Typical Curve Showing Efficiency vs. Particle Size[9]

A large percentage of small particles (under 1 micron diameter) in the gas stream can suppress the generation of the charging corona in the inlet field of an ESP, and thus reduce the number of particles collected. Source personnel should have a good idea of the expected size of the particulate to be collected before purchasing an ESP. Also, the particle size distribution should be predicted for the full range of the operating conditions.

Particle size distribution is usually determined through the use of cascade impactors.

305.8.1 Particle Sizing Techniques

Measurements of particle size distribution in industrial flue gas streams are made for several reasons. The aerosol must be characterized as completely as possible in order to assess the potential for adverse health or environmental effects; emission measurements can be useful as a process monitor; and the aerosol particle size distribution must be known in order to completely quantify the behavior of a control device. Also, particle size measurements on uncontrolled sources are useful in precipitator design.

Any detailed experimental program designed to evaluate an electrostatic precipitator must include measurements on the particle size distributions at the inlet and outlet. These size distributions can then be used to calculate the precipitator collection efficiency versus particle size, or "fractional efficiency curve"

Overall precipitator efficiency is strongly influenced by the inlet particle size distribution. The migration velocity is lowest in the range of 0.1 to 0.3 micron diameters. Because of this, fine particles are more difficult to collect than large particles. Unfortunately, fine particles also contribute more to visible light scattering and opacity, and present a greater health hazard than do the larger particles.

At any given mass concentration, fine particle size distributions accumulate far greater total charge than large particle size distributions. The space charge associated with fine particles frequently causes sparking at relatively low voltage. This is sometimes a limiting factor in precipitator performance. Although most of the mass emitted from a particular pollution source may consist of large particles, in general, the largest number of particles is in the fine particle range.

Thus, high mass collection efficiency does not always imply high number collection efficiency nor does it ensure that a particular opacity standard will be met.

An ideal particle size measurement device would be located in situ and give a real time readout of particle size distributions and particle number concentration over the size range from 0.01 micron to 10 micron diameter. At the present time, however, particle size distribution measurements are made using several instruments which operate over limited size ranges and do not yield instantaneous data.

In-Stack Sampling

Particle sizing methods may involve instruments which are operated in-stack, or out of stack where samples are taken using probes. For in-stack sampling, the sample aerosol flow rate is usually adjusted to maintain near isokinetic sampling conditions in order to avoid concentration errors which result from under or oversampling large particles (greater than 3 micron diameter) which have too high an inertia to follow the gas streamlines in the vicinity of the sampling nozzle. Since many particulate sizing devices have size fractionation points that are flow rate dependent, the necessity for isokinetic sampling in the case of large particles can result in undesirable compromises in obtaining data - either in the number of points sampled or in the validity or precision of the data for larger particles.

In general, particulate concentrations within a duct or flue are stratified to some degree with strong gradients often found for larger particles and in some cases for small particles. Such concentration gradients, which can be due to inertial effects, gravitational settling, and lane to lane efficiency variations in the case of electrostatic precipitators, imply that multipoint (traverse) sampling must be used.

Even the careful use of multipoint traverse techniques will not guarantee that representative data are obtained. The location of the sampling points during process changes or variations in precipitator operation can lead to significant scatter in the data. As an example, rappping losses in dry electrostatic precipitators tend to be confined to the lower portions of the gas streams, and radically different results may be obtained, depending on the magnitude of the rapping losses, and whether single point of traverse sampling is used. In addition, large variations in results from successive multipoint traverse tests can occur as a result of differences in the location of the sampling points when the precipitator plates are rapped. Similar effects will occur in other instances as a result of process variations and stratification due to settling and cyclonic flows.

Choices of particulate measurement devices or methods for individual applications are dependent on the availability of suitable techniques which permit the required temporal and/or spatial resolution or integration. In many instances the properties of the particulate are subject to large changes in not only size distribution and concentration, but also in chemical composition (for example, emissions from the open hearth steel making process). Different methods or sampling devices are generally required to obtain data for long term process averages as opposed to the isolation of certain portions of the process in order to determine the cause of a particular type of emission.

Interferences exist which can affect most sampling methods. Two commonly occurring problems are the condensation of vapor phase components from the gas stream and reactions of gas, liquid, or solid phase materials with various portions of the sampling systems. An example of the latter is the formation of sulfates in appreciable (several milligram) quantities on several of the commonly used glass fiber filter media by reactions involving SO_x and trace constituents of the filter media. Sulfuric acid condensation in cascade impactors and in the probes used for extractive sampling is an example of the former.

If extractive sampling is used and the sample is conveyed through lengthy probes and transport lines, as is the case with several particulate sizing methods, special attention must be given toward recognition, minimization, and compensation for losses by various mechanisms in the transport lines. The degree of such losses can be quite large for certain particle sizes.

305.8.2 Various Particle Sizing Devices

If one were able to design an ideal particle measuring device, the device would have the following features:

1 It would be able to measure the exact size of each particle.

2 It would report data instantaneously without averaging data over some specified time interval.

3 It would determine the complete composition of each particle including shape, density, and chemical nature.

The production of such an instrument is an extremely difficult task. At this time there are devices which incorporate only one or two of these ideal functions. The following sections deal with a few of the available devices, listing advantages and disadvantages of each. Table 305.2 presents the size range capabilities of various measuring devices.

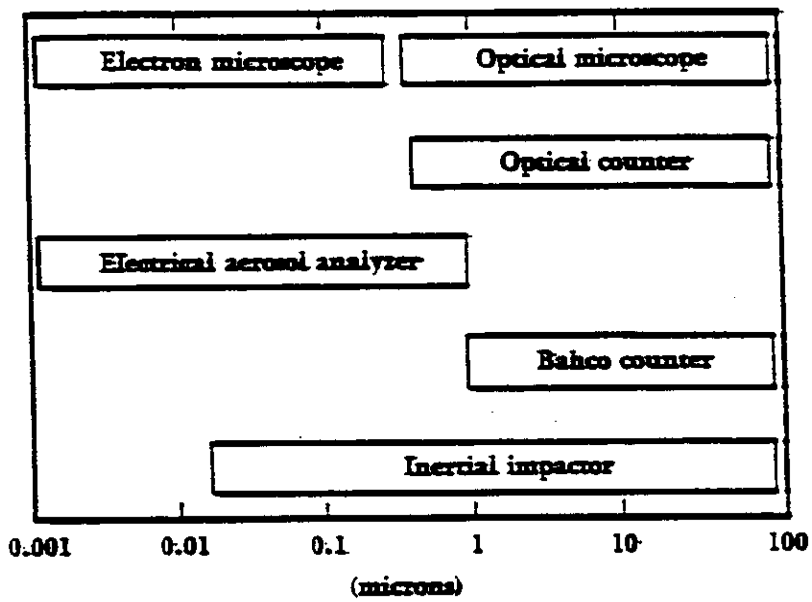


Table 305.2 Size Range Capabilities of Measuring Devices [2]

Microscopy

The microscope is used commonly in particle sizing analysis. With the microscope, one can measure the geometric size of each particle. The determination of particle size is carried out by measuring the size of a number of particles. Particles are sized as they traverse past the eyepiece micrometer. Each particle, presented in a fixed area of the eyepiece, is sized and tallied into a number of size classes. The number of particles sized may range from 100 to several thousand depending on the accuracy desired. This method can be time consuming and extremely tedious.

The particles may be collected by deposition on a glass slide or filter by using a Method 5 sampling train. The glass slide or filter would subsequently be analyzed by a microscope in a lab. The analysis of size distribution of particles collected in the field and transported to the lab must be viewed with great caution. It is difficult to collect a representative sample in the first place, and it is almost impossible to maintain the oroginal size distribution under laboratory conditions. For example, laboratory measurements cannot determine whether some of the particles existed in the process stream as agglomerates of smaller particles. In spite of the limitations of the microscopic method, this method is useful in the determination of some properties of interest.

Electron Microscope

Generally speaking, the chemical composition of the particle cannot be obtained by using an optical microscope. However, a subsequent chemical analysis can be performed on the sample. The electron microscope, on the other hand, can give a detailed chemical analysis of the particle. The electron microscope is used in conjunction with an x-ray diffraction attachment to determine the molecular weight of the particle. Particles with molecular weights greater than carbon can be determined by the amount of radiation diffracted by each particle analyzed.

The optical microscope can measure particles from about 0.5 micron to about 100 microns in diameter. Electron microscopes can measure particles with diameters as small as 0.001 micron. This could be useful for examining extremely minute particles.

Optical Counters

Optical particle counters have not been widely used for particle sizing because they cannot be directly applied to the stack exhaust gas stream. The sample must be extracted, cooled and diluted before entering the counter. This procedure must be done with extreme care to avoid introducing serious errors in the sample. The major advantage of the counter is its capability of observing emission (particle) fluctuations on an instantaneous level. One can size particles as small as 0.3 micron with the optical counter.

Optical particle counters work on the principle of light scattering. Each particle in a continuously flowing sample stream is passed through a small illuminated viewing chamber. Light scattered by the particles is sensed by the photodetector during the time the particle is in the viewing chamber (see figure 305.6). The

300 THEORY AND DESIGN

intensity of the scattered light is a function of particle size, shape, and index of refraction. Optical counters will give reliable particle size information if only one particle is in the viewing chamber at a single time. The simultaneous presence of more than one particle can be interpreted by the photodetector as a larger sized particle. This error can be avoided by maintaining sample dilution less than 300 particles per cubic meter.

A disadvantage of the optical counter is the dependence of calibration of the instrument upon the index of refraction and shape of the particle. Errors in counting can also occur from the presence of high concentrations of very small particles which also occur from the presence of high concentrations of very small particles which are sensitive to the light wavelength used.

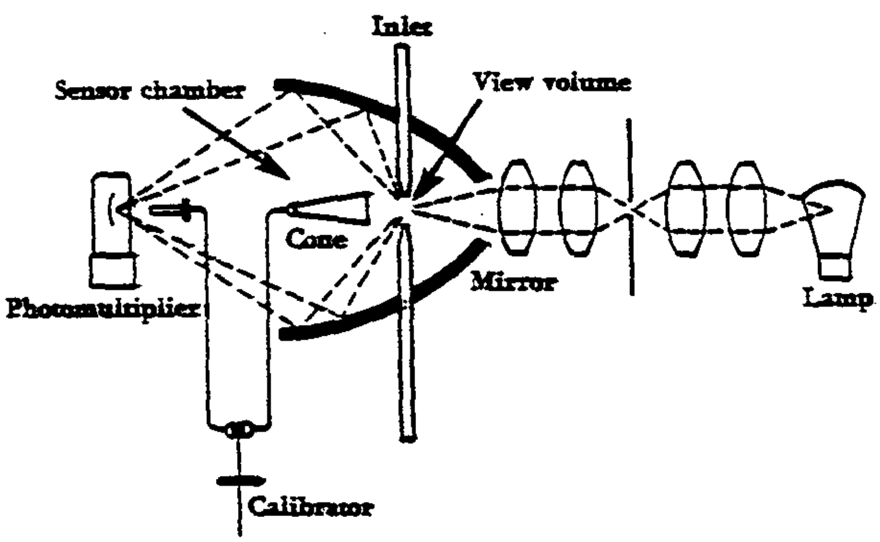


Figure 305.6 Operating Principle for an Optical Particle Counter [2]

Electrical Aerosol Analyzer

The electrical aerosol analyzer (EAA) is an aerosol size distribution measuring device that was commercially developed at the University of Minnesota. The EAA uses an electric field, which is set at an intensity dependent upon the size and mass of the particle, to measure the mobility of a charged aerosol. The analyzer operates by first placing a unipolar charge on the aerosol being measured, and measuring the resulting mobility distribution of the charged particles by means of a mobility analyzer.

Charged Aerosol

Charged particles enter through a narrow passage and experience a radial force toward the central cylinder due to the applied field. By moving the sampling groove axially, or by varying the applied field, the mobility of the charged particles can be measured. One type of EAA is shown in figure 305.7.

The EAA has been used for source analysis by pulling a sample from the stack into the chamber and introducing the gas stream into the analyzer. The instrument requires that enough particles pass through the chamber so that a charge can be detected. The concentration range for most efficient operation of the EAA is from 1 to 1000 microgram per cubic meter. Since stack gas concentrations usually exceed 1000 micrograms per m^3, sample dilution with clean air is required. No information on the chemical composition of the particles is possible since the particles are not collected. The major advantage of the EAA is that the instrument can measure particles form 0.003 to 1.0 micron in diameter.

Bahco Microparticle Classifier

The Bahco (figure 305.8) is a versatile particle classifier used for measuring powders, dust, and other finely divided solid materials. The Bahco's working range is approximately 1 to 60 microns. Developed in the 1950's, the Bahco has lost some of its initial appeal to more recently developed techniques.

The Bahco uses a combination of elutriation and centrifugation to separate particles in an air stream. Particles can be collected onto a filter by using a Method 5 sampling train. The collected particles are subsequently analyzed in the lab.

A weighed sample, usually 5 grams, is introduced into a spiral-shaped air current to separate the particle fractions. The larger particles overcome the viscous forces of the fluid and migrate to the wall of the chamber, while the

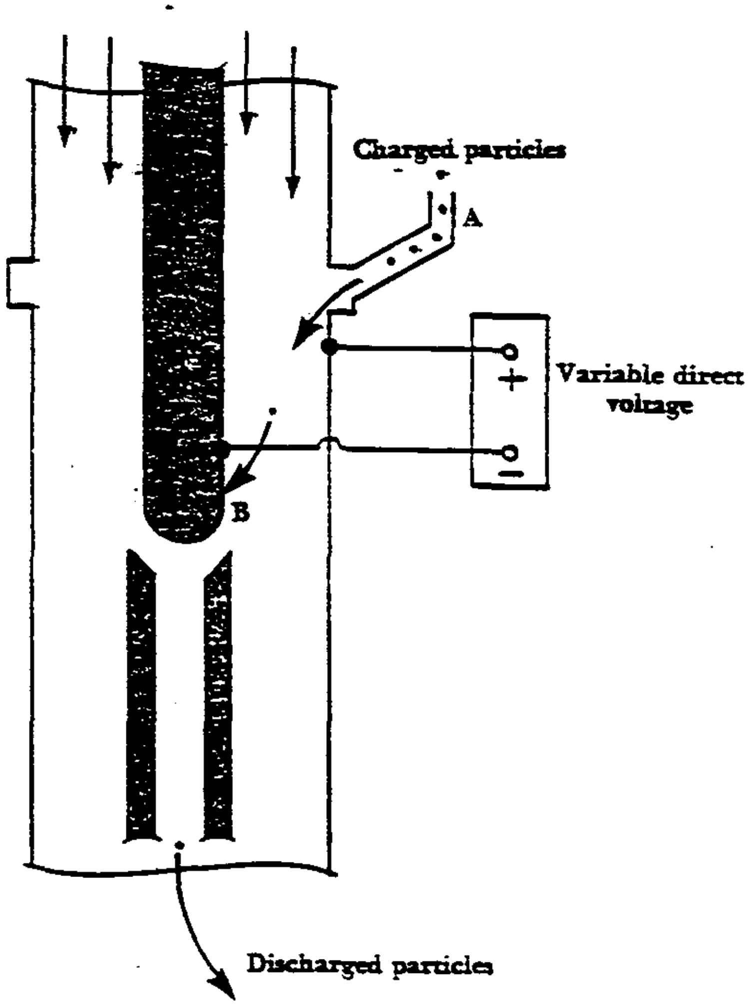


Figure 305.7 Coaxial Cylinder Mobility Analyzer [2]

smaller particles remain suspended. After the two size fractions are separated, one of them is reintroduced into the device and is fractionated further. A different spin speed is used to give a slightly different centrifugal force. This is repeated as many times as desired to give an adequate size distribution. The measurements are grouped into discrete size ranges (i.e., 40 - 60 microns, 20 - 40 microns, etc.).

The Bahco provides information on the aerodynamic size of the particles. This data can be translated into settling velocity information useful in the design of emission control devices. Several hours are required to complete the fractionation analysis. Once the particles have been fractionated into the discrete ranges, a chemical analysis can be done on the collected particles.

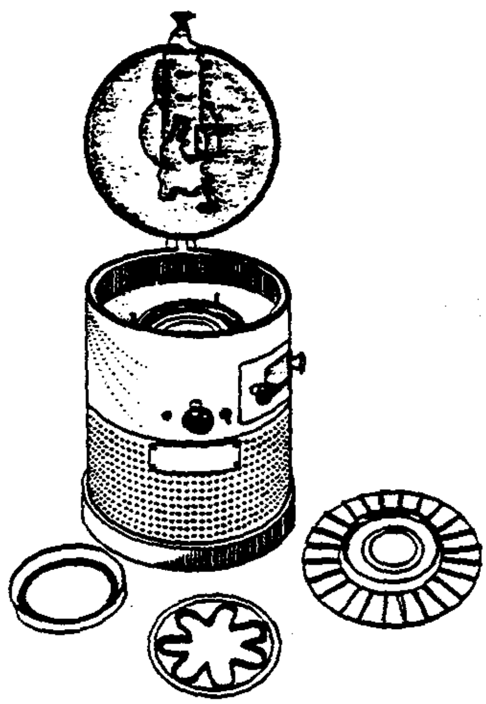


Figure 305.8 Bahco Sampler [2]

Some of the major drawbacks of the Bahco are that:

1 The working range is limited between 1 and 60 microns;

2 Care must be exercised when measuring certain types of particles, especially those which are friable or hygroscopic;

3 The sample may not be representative due to particle agglomeration either in the stack or during the transfer of the collected sample in the lab;

4 The length of time required for analysis is several hours or more;

5 The size grading regimes are not as sharp as with newer devices.

Impactors

Inertial impactors are commonly used to determine the particle size distribution of exhaust streams from industrial sources. Inertial impactors measure the aerodynamic diameter of the particles. The inertial impactor can be directly attached to a Method 5 sampling train and can be easily inserted into the stack of an industrial source.

The mechanism by which an impactor operates is illustrated in figure 305.9. The impactor is constructed using a succession of stages each containing orifice openings with an impaction slide of collection plate behind the openings. In each stage, the gas stream passes through the orifice opening and forms a jet which is directed towards the impaction plate. The larger particles will impact on the plate if their momentum is large enough to overcome the drag of the air stream as it moves around the plate. Since each successive orifice opening is smaller than those on the preceeding stage, the velocity of the air stream, and therefore that of the dispersed particles, is increased as the gas stream advances through the impactor. Consequently, smaller particles eventually acquire enough momentum to break away from the gas streamlines to impact on a plate. A complete particle size classification of the gas stream is therefore achieved.

Typical impactors consist of a series of stacked stages and collection surfaces. Depending on the calibration requirements, each stage contains from one to as many as 400 precisely drilled jet orifices, identical in diameter in each succeeding stage (figure 305.10). Adhesive, electrostatic, and van der Waals forces hold the particles to each other and to the collection surfaces. Moreover, the

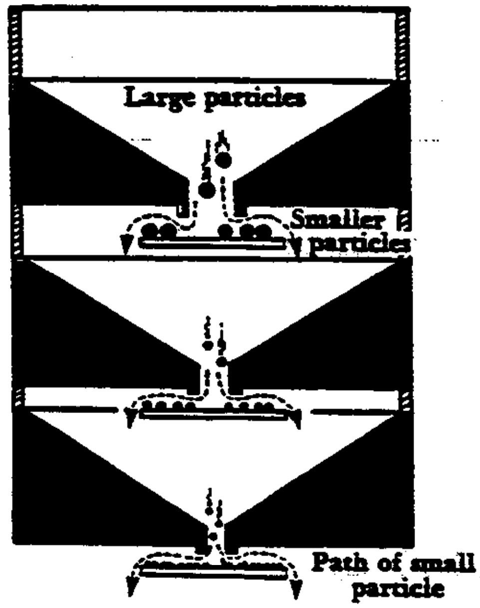


Figure 305.9 Operation of an Inertial Impactor [2]

particles are not blown off the collecting plate by the jets of air because these jets follow laminar flow paths so that no turbulent areas exist. This results in complete dead air spaces over and around the samples.

Particles are collected on preweighed individual stages, usually filters made of glass fiber or thin metal foil. Once the sample is complete, the collection filters are weighed again, yielding particle size distribution data for the various collection stages. Occasionally there are some dusts that are very difficult to collect, and require grease on the collection filter for adequate particle capture. Once the particles have been fractionated into discrete ranges, a chemical analysis can be performed on the collected particles.

The effective range for measuring the aerodynamic diameter is generally between 0.3 and 20 microns. Some vendors have claimed size fractionation as small as 0.02 micron with the use of 20 or more stages. Impactors are one of the most useful devices for determining particle size. This is because of the impactor's compact arrangement, mechanical stability, and its ability to draw a sample directly from a stack. In addition, the impactor measures the aerodynamic diameter of particles, which describes the movement of the particles in a gas stream. Particle movement information is extremely useful in designing air pollution control equipment.

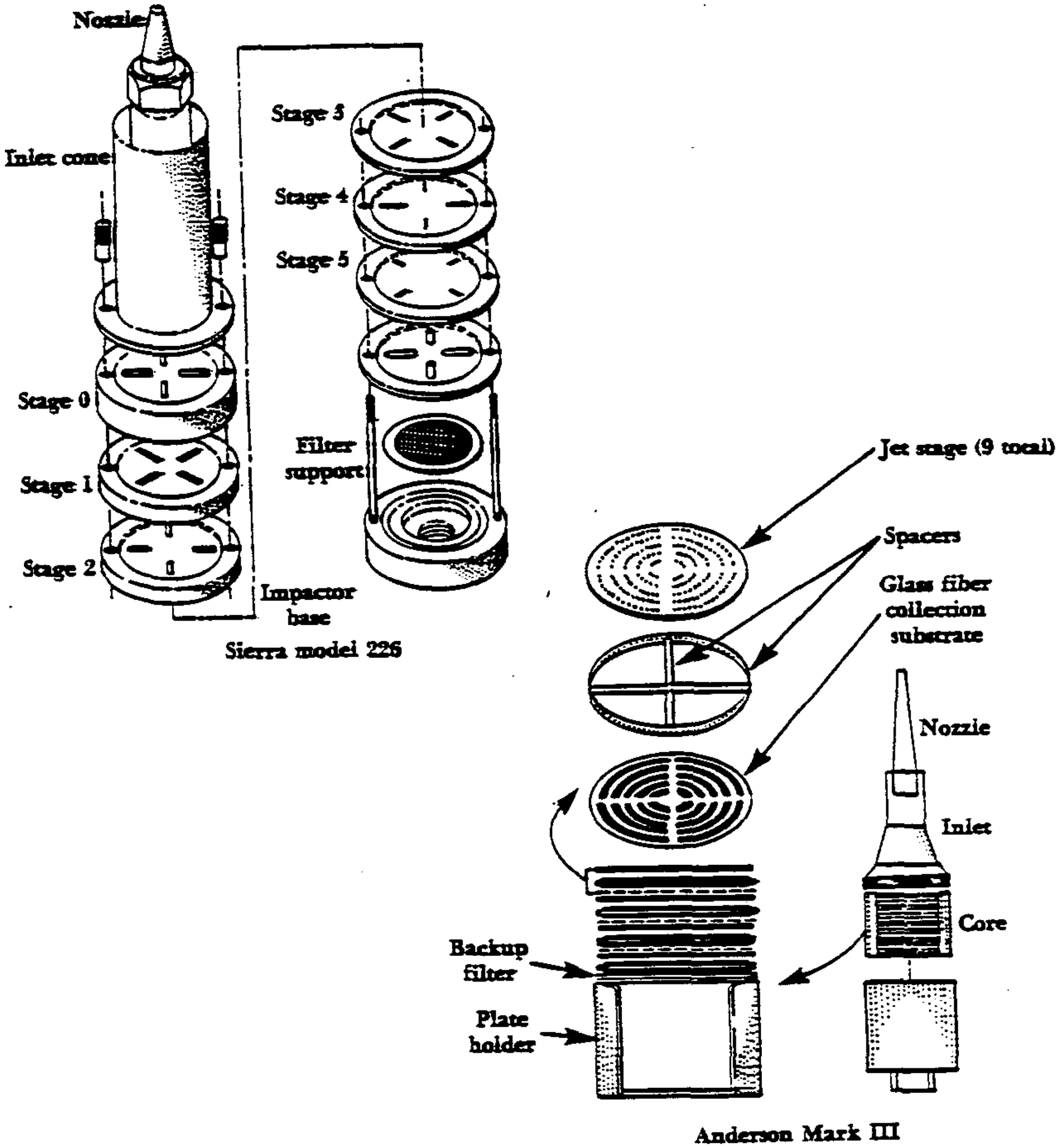


Figure 305.10 Schematics of Two Commercial Cascade Impactors [2]

305.9 SPARK RATE

Spark rate is usually seen as an operating parameter affecting ESP performance. However, a range of optimum spark rates can and should be designed for by specifying the power control devices used in the precipitator. Therefore, spark rate can be treated as a design factor affecting ESP performance.

Optimal Sparking Rate

"Sparking" refers to short duration internal arcing between discharge and collection electrodes. It is a sudden rush of localized electric current through the gas layer between the two electrodes. In general, it is very desirable to operate at voltages high enough to cause some sparking but not at a frequency such that the electric field constantly collapses. Occurrence of a spark counteracts high ESP performance since it causes an immediate, short term collapse of the precipitator field. Consequently, less useful power is applied to capture particles. There is, however, an optimal sparking rate where the gains in particle charging are just offset by corona current losses from sparkover due to the collapse of the electric field. For optimum efficiency, the electric field should be as high as possible. This is accomplished by applying a high voltage to the discharge electrode.

The voltage control devices operate in the following manner; increases in voltage will cause a greater spark rate between the discharge and collection electrodes. The objective of power control is to maintain corona power input at this optimal sparking rate. This can be accomplished by momentarily reducing precipitator power whenever excessive sparking occurs.

When a voltage controller is set on "manual", the corona voltage will not exceed the set value. However, if conditions within the precipitator are such that sparking occurs at a voltage lower than the set value, uncontrolled sparking will occur.

Micro-processors

Modern automatic power control devices using microprocessors have a far quicker response time to sparking than did the older units. As a result, excessive sparking is curbed. The optimum sparking rate for one of these modern systems may range from 30 to 60 per minute, while a non-microprocessor system may have an optimum sparking rate between 50 and 150 per minute.

Some level of sparking within an ESP is necessary. This is because sparking indicates that the secondary voltage is as high as possible for the prevailing process conditions. In fact, some studies indicate that at times sparking may be conducive to higher precipitator efficiency. Sparking dislodges particulate deposits on the electrodes in the immediate vicinity of the spark. This can be useful in cleaning hardened deposits off the electrodes, especially when the rapping system is ineffective. However, sparking between clean wires and plates causes electrical corrosion of the wires by the same mechanism, making them more prone to failing under tension.

Sparking between the discharge electrodes and grounded support frames is always detrimental to precipitator performance.

306 ESP COMPONENTS

This section briefly describes major ESP components and presents current nomenclature for a typical ESP configuration. Figure 306.1 shows a typical wire-weight ESP.

306.1 DISCHARGE ELECTRODES

Discharge electrodes are also referred to as corona electrodes, corona wires, cathodes, and high-voltage electrodes.

The discharge electrodes are maintained at high voltage during operation of the ESP. The high voltage electrodes ionize the gas and establish the electric field, which imparts a charge to particles and causes precipitation upon grounded collection plates.

Barbs

Discharge electrodes are metal, of a type determined by the compostion of the gas stream. The form of the electrodes varies. They may be circular or rectangular in cross-section, and may have spikes or barbs, and may be stamped or formed. Figure 306.2 shows various configurations.

Discharge electrodes are mounted in a variety of ways. They may be suspended by an insulating superstructure with weights (also known as bottles) at the bottom holding them in place, or they may be rigidly mounted on masts or frames. Regardless of how they are mounted, they must be stabilized against swinging in the gas stream. Examples of wire-weighted and rigid wire systems are shown in figures 306.3 and 306.4.

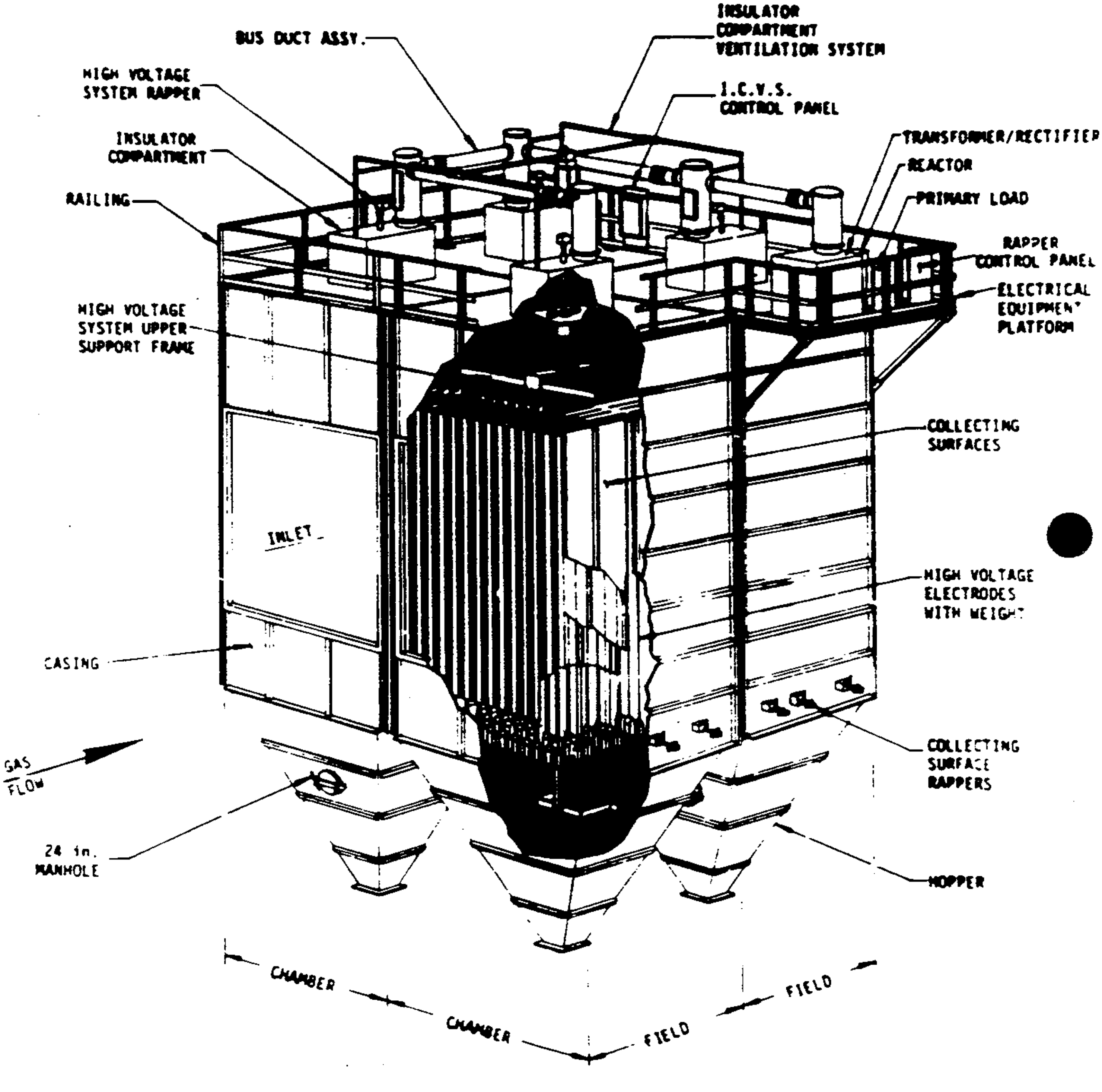


Figure 306.1 Typical Wire Weight ESP [3]

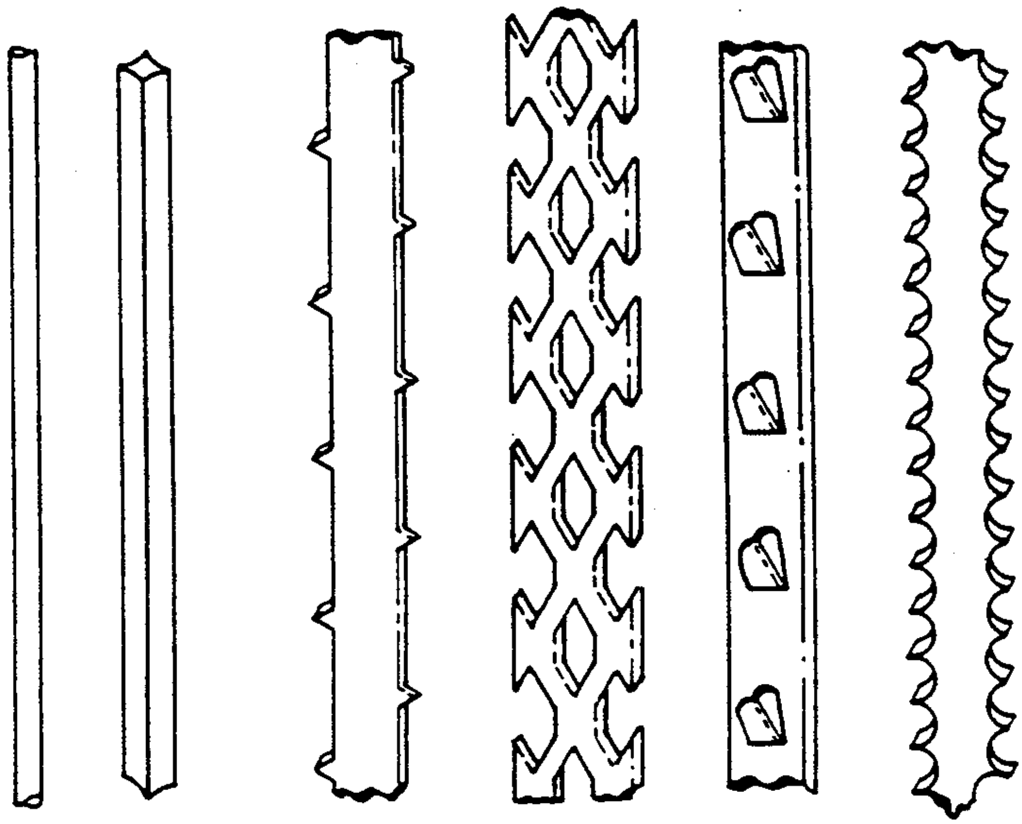


Figure 306.2 Typical Forms of Discharge Electrodes [10]

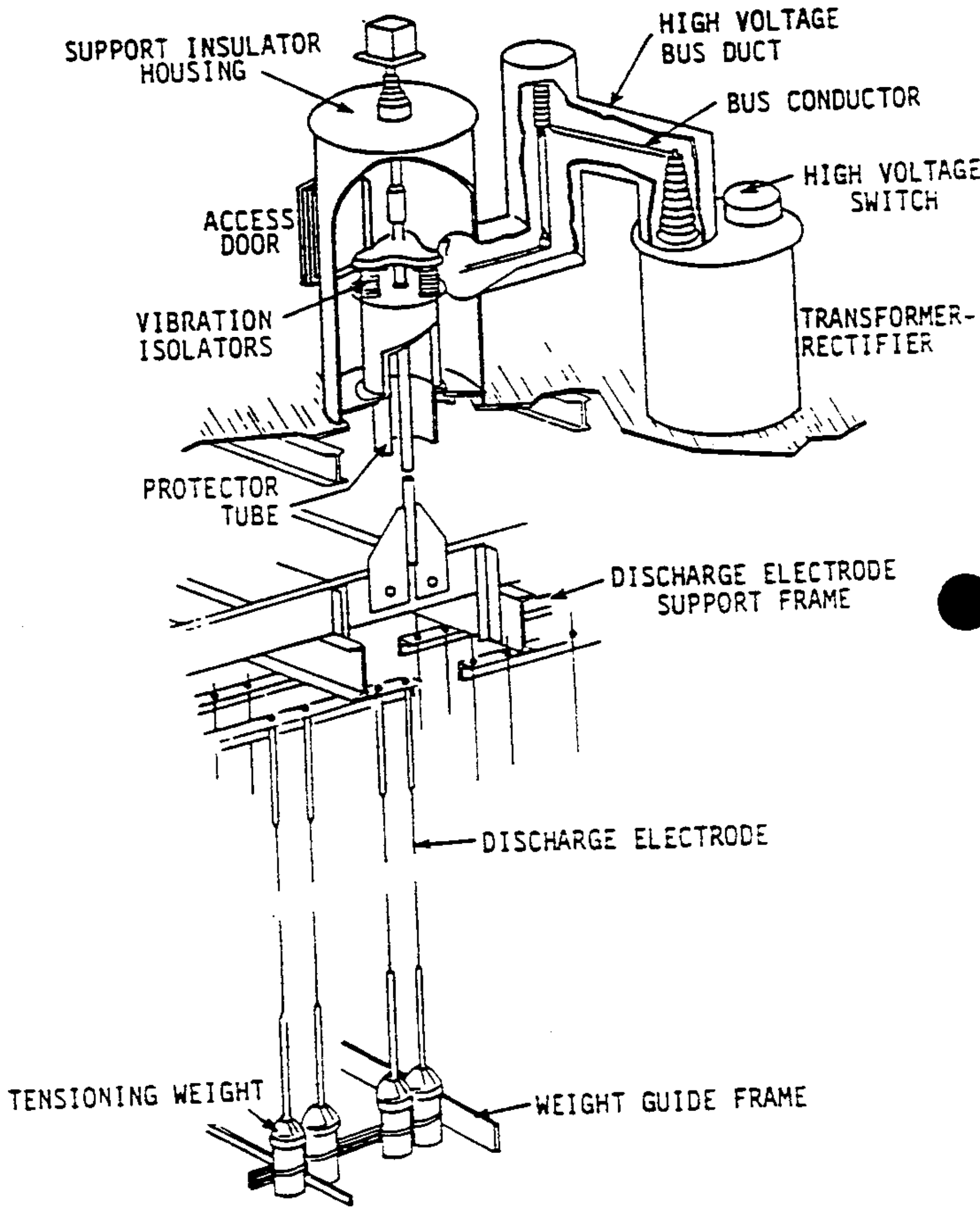


Figure 306.3 Precipitator Charging System and Wire Hanging System [7]

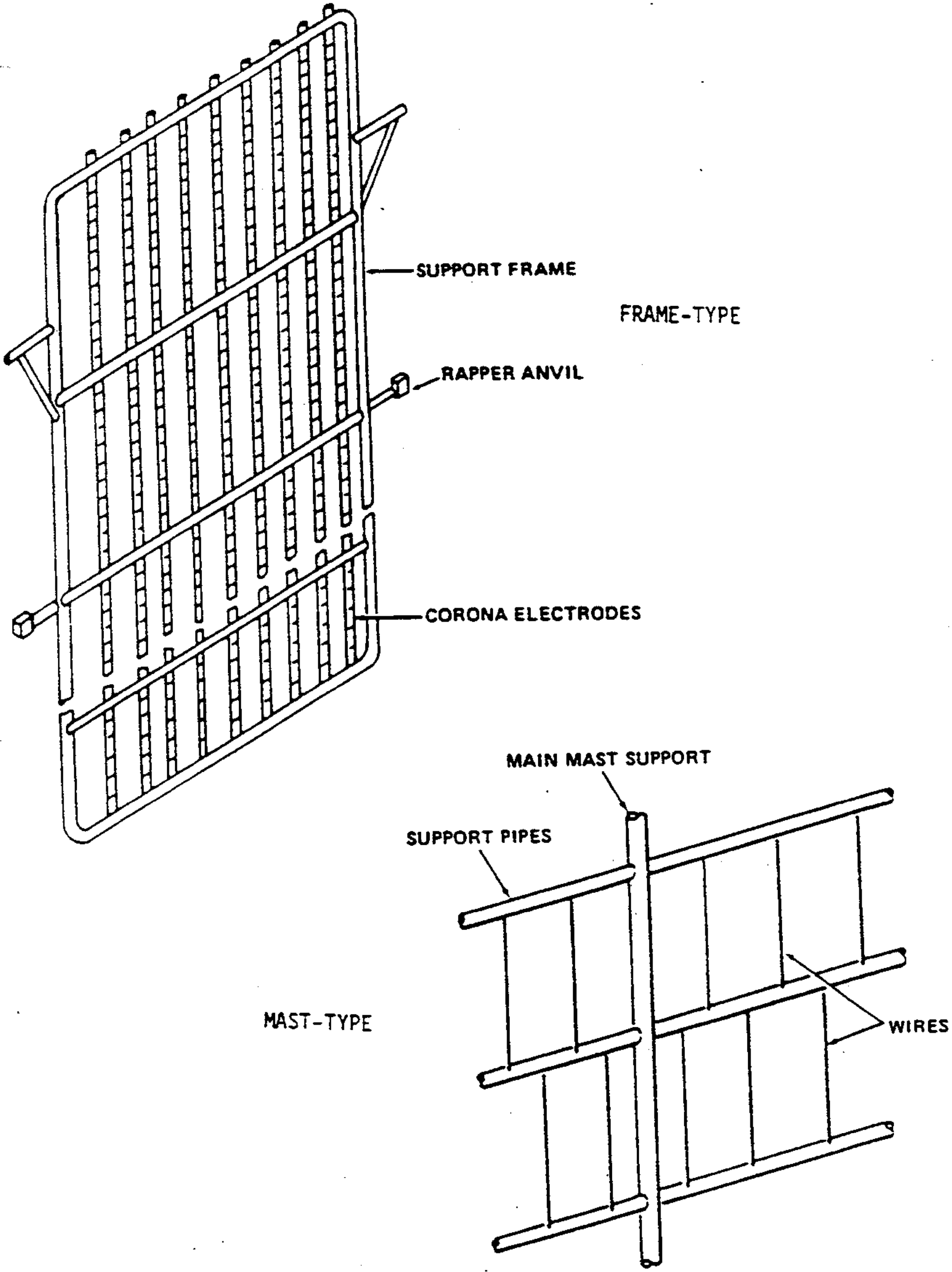


Figure 306.4 Supported Electrode Structures [10]

306.2 COLLECTION ELECTRODES

Baffle Arrangement

Collection electrodes are the grounded metal plates upon which the dust collects. Many shapes of flat collecting electrodes are used in ESPs, as shown in figure 306.5, and some ESPs are designed with cylindrical collection surfaces. All plate configurations are designed to maximize the electric field and to minimize dust reentrainment. All collection plates have a baffle arrangement to minimize gas velocities near the dust surfaces as well as to provide stiffness. Collection plates are commercially available in lengths ranging from 3 feet to 9 feet (1 to 3 meters) and heights from 9 feet to 50 feet (3 to 15 meters). Generally, these panels are grouped within the precipitator to form independently rapped collection modules. The total effective length of these plates divided by their effective height is referred to as the aspect ratio. Aspect ratios larger than 1.0 provide longer residence time for the gas and increase collection efficiency, all other factors being equal.

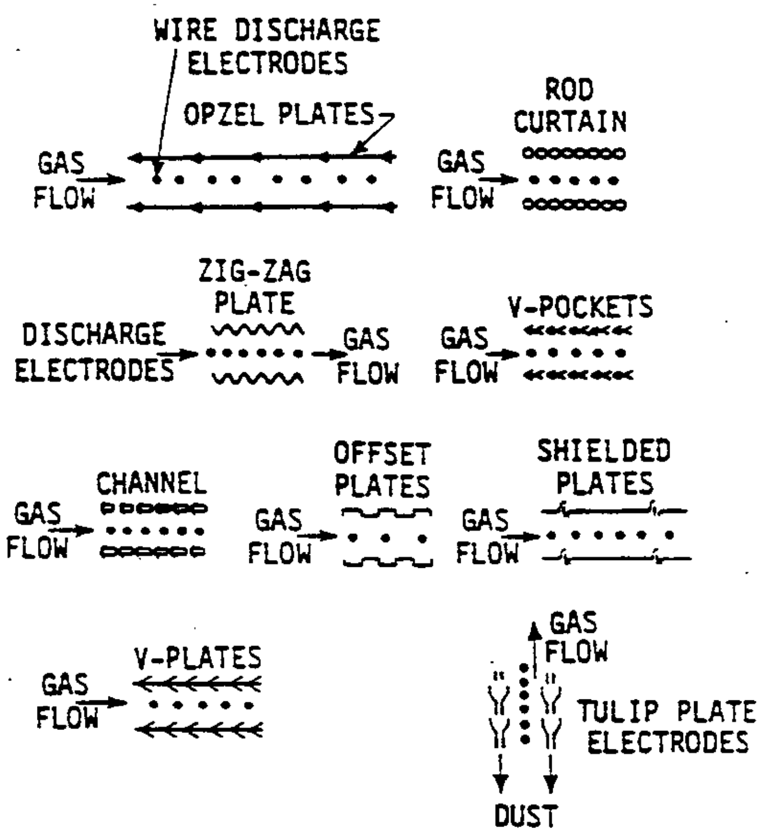


Figure 306.5 Various Designs of Collection Electrodes [11]

306.3 SHELL

The precipitator casing is of gas-tight, weatherproof construction. Major casing parts are the inlet and outlet connections, the shell and hoppers, inspection doors, and insulator housing. The casing is fabricated of steel of a type suitable for the application (type of process, heat range, etc.). The shell is reinforced to handle maximum positive or negative pressure, support the weight of the internals, and sustain environmental stresses such as those imposed by wind, snow, and earthquake. The shell and insulator housing form a grounded steel chamber, completely enclosing all the voltage equipment to ensure the safety of personnel.

Grounded

306.4 HOPPERS

Dust hoppers are required for temporary storage of the collected dust. The most common hopper design is pyramidal, converging to a square or round discharge area.

To prevent plugging, hoppers should be kept clean, dry, and if the dust is moisture-laden, warm. Many hoppers do not require vibrators, but it is economical to install mounting devices for future installation of vibrators should operation show that they are necessary. If insulation does not keep the hopper warm enough, additional heating of the hoppers may be required for effective performance.

Frequently, hoppers are baffled at the divisions between two dust-plate sections to prevent gas from bypassing the precipitator.

Access to hoppers should be by external, key-interlocked doors to prevent dangerous dust accumulations on the interior side of the door. Enough ''poke hole'' ports should be provided to allow for cleaning a blockage at the discharge.

Key - Interlocked Doors

Systems for removal of dusts accumulated in hoppers include containers, dry vacuum, wet vacuum, screw conveyors, and scrape bottom systems.

306.5 RAPPERS AND VIBRATORS

Rapping systems are incorporated in an ESP to dislodge dust from the collecting and discharge surfaces; their effectiveness and reliability are essential. Generally available types of rappers are pneumatic or electromagnetic impulse units, electric vibrators, and mechanical hammers.

Rapper systems are designed to be compatible with the internal suspension system and the number of surfaces affected by the rapping shock. Pneumatic rappers supply the most shock and dislodge tenacious dusts most readily. It is important in any rapper system that all hardware is designed to withstand high energy forces.

Pneumatically or electromagnetically operated rappers may be of the impact or vibratory type. The impact type rapper functions by lifting a weight to a controlled height and then allowing it to fall against an anvil, which transmits the shock to the discharge and collection surfaces. Vibratory rappers impart vibrations to the discharge and collecting surfaces by means of rods extending through the precipitator shell.

Rapping hammers, which are used with rigid discharge electrode ESPs, remove dust very efficiently, but when installed in a moving gas stream may require frequent maintenance. One type of tumbling hammer design is illustrated in figure 306.6.

The number and size of rappers and rapping frequencies vary with the manufacturer and the nature of the dust. Generally one rapper unit is required for 1200 ft^2 to 1600 ft^2 (110 to 150 m^2) of collecting area. Discharge electrode rappers serve from 1000 ft to 7000 ft (350 to 2000 m) of wire per rapper. Intensity of rapping intervals are adjustable over a range of approximately 30 to 600 seconds.

Reentrainment

The paramount consideration in rapping is to provide acceleration to dislodge the dust without causing excessive reentrainment.

MIGI

The magnetic-impulse, gravity-impact (MIGI) rapper, shown in figure 306.7, is a solenoid electromagnet consisting of a steel plunger surrounded by a coil, both enclosed in a watertight steel case. The control unit contains all the components

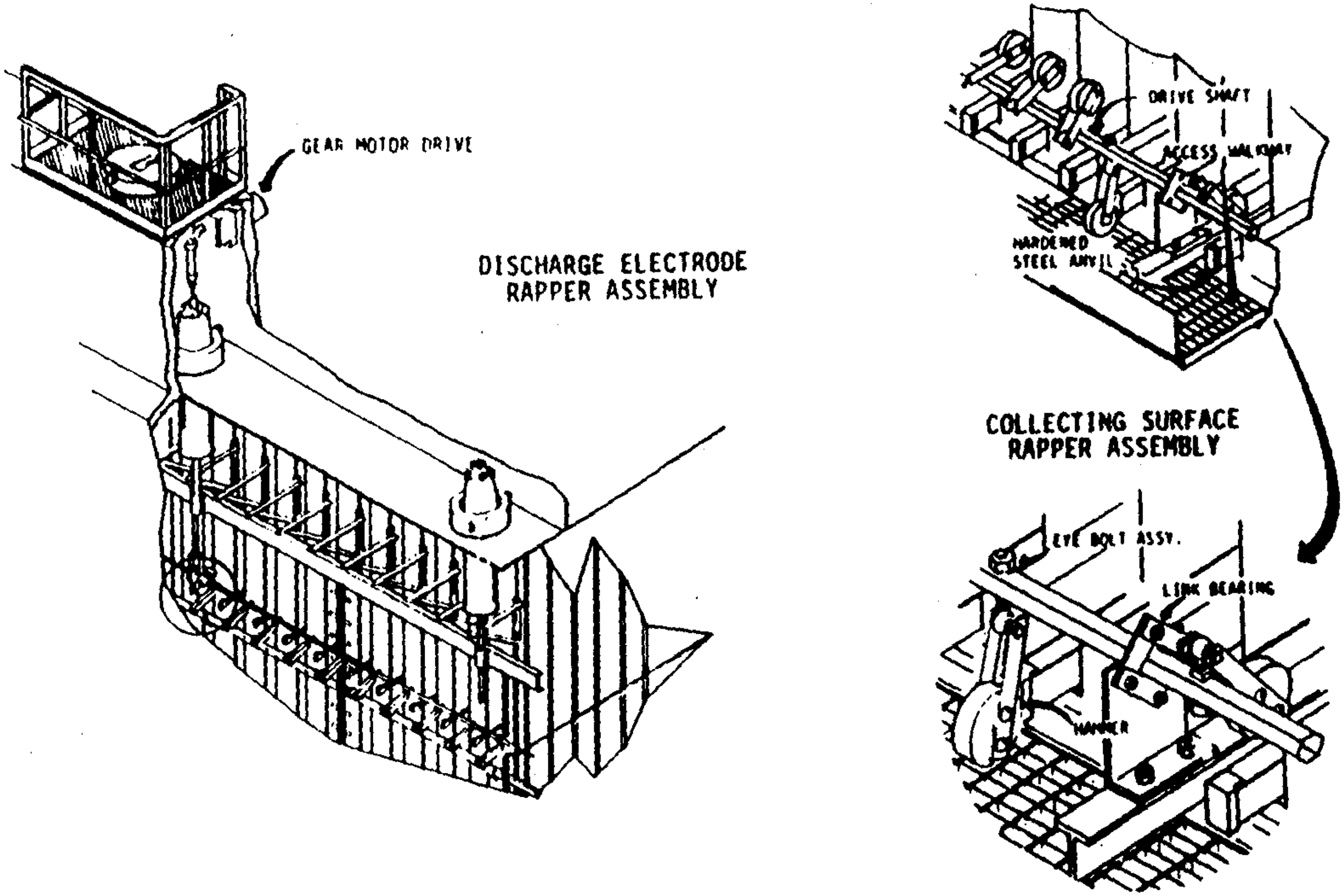


Figure 306.6 Tumbling Hammer Assembly [3]

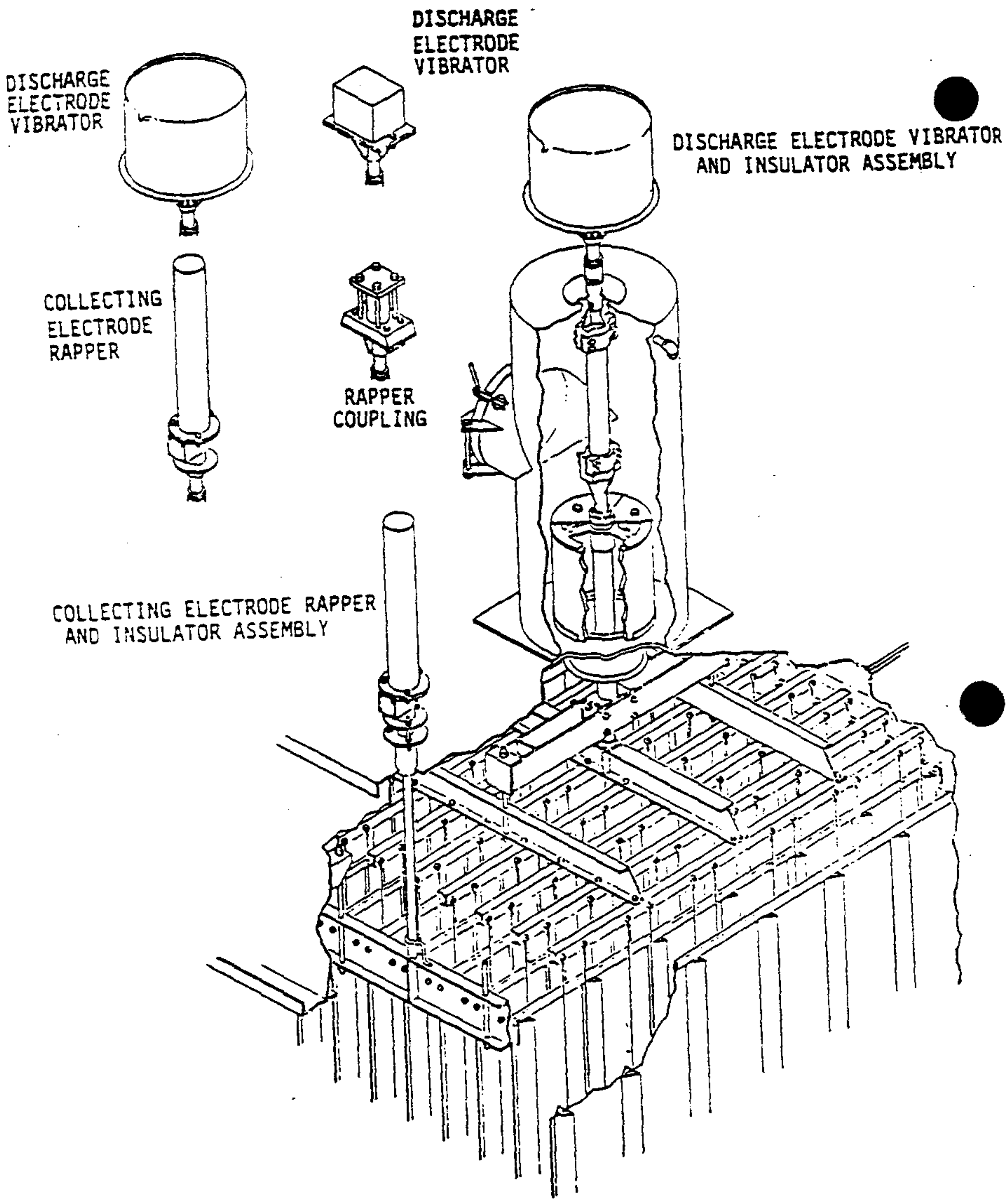


Figure 306.7 Vibrator and Rapper Assembly [12]

(except the rapper) needed to distribute and control the power to the rappers for optimum precipitation. The electrical controls provide separate adjustments so that the rappers can be assembled into different groups, each of which can be independently adjusted from zero to maximum rapping intensity. The controls are adjusted manually to regulate the release of dust from the collecting plates and prevent undesirable "puffing" from the stack.

Puffing

During normal rapping operation, a short-duration direct current (DC) pulse through the coil of the rapper supplies the energy to move the steel plunger. The plunger is raised by the magnetic field of the coil and then is allowed to fall back and strike a rapper bar, which is connected to a bank of collecting electrodes within the precipitator. The shock transmitted to the collecting electrodes dislodges the accumulated dust.

In some applications, the magnetic-impulse, gravity-impact rapper is used to clean the precipitator discharge wires. For this purpose, the rapper strikes the electrode supporting frame in the same manner, except that an insulator isolates it from the high voltage of the frame.

Mechanical Rappers

Some installations have mechanical rappers, in which a single hammer assembly mounted on a shaft raps each frame (see figure 306.6). A low-speed gear motor is linked to the hammer shaft by a drive insulator, fork, and linkage assembly. Intensity of rapping is governed by the hammer weight, and frequency is governed by the speed of rotation of the shaft.

Vibrators

A vibrating system creates vibrations in either the collecting plates or the discharge wires to dislodge accumulations of particles. Vibrators are not normally used to clean the collecting electrodes of precipitators that collect fly ash.

The vibrator is an electromagnetic device, the coil of which is energized by alternating current. Each time the coil is energized, the resulting vibration is transmitted through a rod to the high-tension wire supporting frame or collecting plates (see figure 306.7). The number of vibrators depends on the number of high-tension frames or collecting plates in the system.

The control unit contains all devices for operation of the vibrators, including means of adjusting the intensity and period of vibration. Alternating current is supplied to the discharge wire vibrators through a multiple cam-type timer to provide sequencing and duration for energization of the vibrators.

Dust Buildup

For each installation, a certain intensity and period of vibration will produce the best collecting efficiency. Low intensity will result in heavy buildup of dust on the discharge wires. Dust buildup reduces the sparkover distance between the electrodes, thereby limiting the power input to the precipitator. It also tends to suppress the formation of negative corona and the production of unipolar ions required for precipitation. Further, dust buildup alters the normal distribution of electrostatic forces in the treatment zone and can lead to oscillation of the discharge wires and the high-tension frame.

Large Particles Reentrained

Recent studies have investigated reentrainment caused by rapping in terms of the percentage of materials reentrained and its particle size distribution. One report describes the testing of six full-scale electrostatic precipitator installations. Losses from rapping ranged from over 80 percent of the total mass emissions from one hot-side unit to 30 percent of emissions from cold-side units. The losses consist mostly of relatively large particles, primarily those larger than 2.0 microns in diameter. Tests of a pilot-scale precipitator showed that rapping emissions decreased as time between raps was increased.

Because reentrainment from rapping can be a significant portion of the total emissions, it is important that the rapping system is adjusted to minimize reentrainment.

306.6 GAS FLOW DISTRIBUTION

Guide Vanes

Proper gas flow distribution is critical for optimum precipitator performance. The plant flue system and its connections to the ESP are more important than the precipitator itself in determining the quality of gas flow through the precipitator. A set of guide vanes, which is the most common device used to direct gas flow, allows a streamlined flow of gas. Figure 306.8 illustrates how guide vanes prevent flow separation.

Diffusion Screens

Diffusion screens and baffles are also used to reduce turbulence and maintain uniform gas flow. A diffuser consists of a woven screen or a thin plate with a regular pattern of small openings. The effect of a diffuser is to break large-scale turbulence into a large number of small-scale turbulent zones, which in turn decay rapidly and in a short distance coalesce into a relatively low-intensity turbulent flow field. Two or three diffusers may be used in series to provide better flow than could be achieved with only one diffusion plate (see figure 306.9). Cleaning of the gas distribution devices may entail rapping.

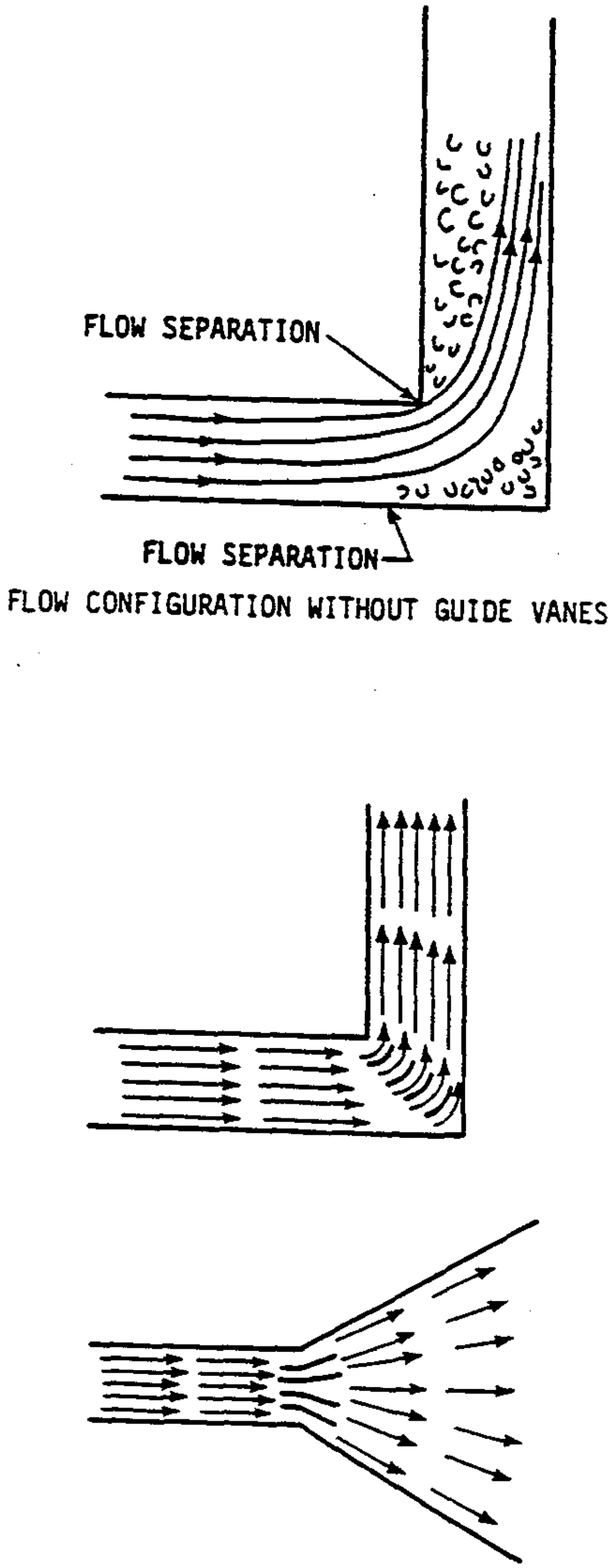


Figure 306.8 Action of Guide Vanes [13]

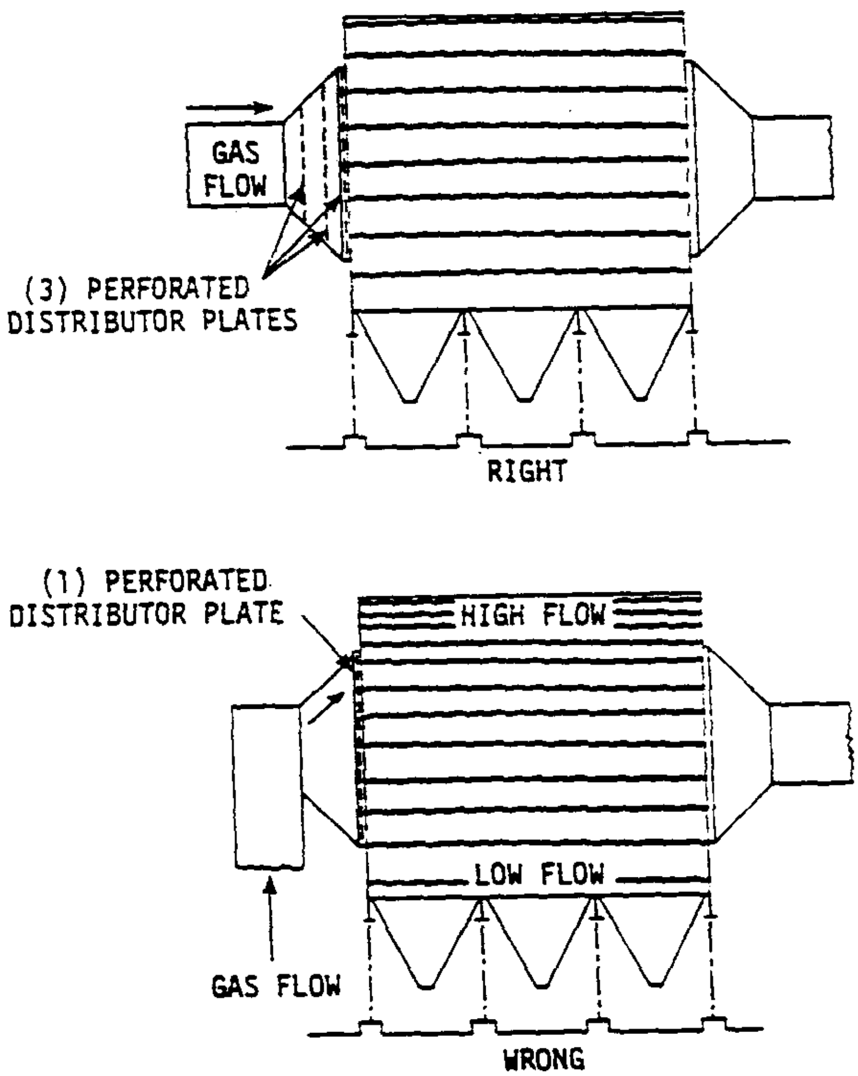


Figure 306.9 Effect of Different Gas Distribution Methods [14]

In multiple-chamber ESPs, louver-type dampers should be used for gas proportioning instead of guillotine shutoff dampers, because guillotine-type dampers tend to destroy proper gas distribution to a chamber.

306.7 HIGH VOLTAGE EQUIPMENT

The electrical energizing sets consist of high-voltage silicon diode power packs developed specifically for the high loads required for supplying high-voltage direct current to electrostatic precipitators.

The power supply system consists of four components: a step-up transformer, a high-voltage rectifier, a control element, and a control system sensor. The system is designed to provide voltage at the highest level without causing arc-over (sparking) between the electrode and the collection surface. The automatic control system maintains the optimum voltage value, adjusting to fluctuations in characteristics and concentrations of the dust.

The way in which a precipitator is energized has a strong effect on its performance. Electrical energization involves the number and size of the transformer-rectifier (T-R) sets, number of electrical sections in half wave/full wave (HW-FW) operation, and changes in the voltage/current characteristics as precipitation proceeds in the direction of gas flow.

Corona Power

Corona power is another important design factor, along with being a quantitative indicator of collection performance on an operating ESP (see section 403.4.1 for use in ESP performance evaluations). Corona power is a measure of the presence and intensity of the electrical energy (driving force) used in the precipitation process. The extent of corona power used in precipitation is measured by the primary or secondary voltage and current meters. Although factors other than corona power are responsible for determining the performance level (e.g., electrode alignment, rapper operation and sequence, etc.), the influence of these degradation factors is reflected by corona power levels. When problems with electrode alignment or rapper operation arise, they evidence themselves by reducing the operating voltage and current levels of the fields affected. Conversely, high corona power levels can compensate for some design shortcomings. Since corona power is the product of voltage and current, reduced operating voltage and current levels produce reduced corona power levels proportional to their products.

Power Optimization

During normal operation, the power to the precipitator is optimized by automatic power controls, which vary the power parameters in response to a signal generated by the spark rate. The automatic controls also make the circuit sensitive to overload and provide safety controls in the event that spark level cannot be reached.

The automatic control circuit controls spark rate, current, and voltage. Although earlier ESPs used saturable reactors for power control, modern ESPs use silicon controlled rectifiers (SCR); this section discusses only SCRs. The silicon controlled rectifiers provide a wide range of precipitator current, and the current-limiting reactor limits the swinging of current during precipitator sparking.

SCR

The SCRs act as a variable impedance in controlling the flow of power in the circuit. An SCR is a three-junction semi-conductor that is normally an open circuit until an appropriate signal is applied to the gate terminal, at which time it rapidly switches to the conducting state. The flow of current is controlled by the forward blocking ability of the SCRs, which in turn is controlled by the firing pulse to the gate of the SCR. The current-limiting reactor reshapes the wave form of the current and the peak that occurs during sparking. Current wave form with and without SCRs is illustrated in figure 306.10.

Conventional Spark Control

Conventional spark control is based on storing electrical pulses in a capacitor for each spark that occurs in the precipitator. If the voltage of the capacitor exceeds a preset reference value, an error signal will phase the mainline SCRs back to a point where the sparking will stop. Usually this snap-action type of control tends to overcorrect and thus leads to longer downtime than is desirable. At low sparking rates, about 50 sparks per minute, the overcorrection is more pronounced and voltage is reduced for a longer period, with subsequent loss of dust and low ESP efficiency.

Proportional Spark Control

Proportional control, another method of spark control, is also based on storing electrical pulses for each spark that occurs in the precipitator. In this system, however, phaseback of the mainline SCRs is proportional to the number of sparks in the precipitator. The main advantage of proportional control over conventional spark control is that the precipitator determines its own optimum spark rate, based on four factors: temperature of the gas, dust resistivity, dust concentration, and internal condition of the precipitator. With proportional spark rate control, therefore, the precipitator determines the optimum operating parameters, whereas with conventional spark control, the operator selects the parameters, which may not be optimum.

Some precipitators operate at the maximum voltage or current settings on the power supply with no sparking. In collection of low-resistivity dusts, where the electric field and the dust deposit are insufficient to initiate sparking, a no-spark

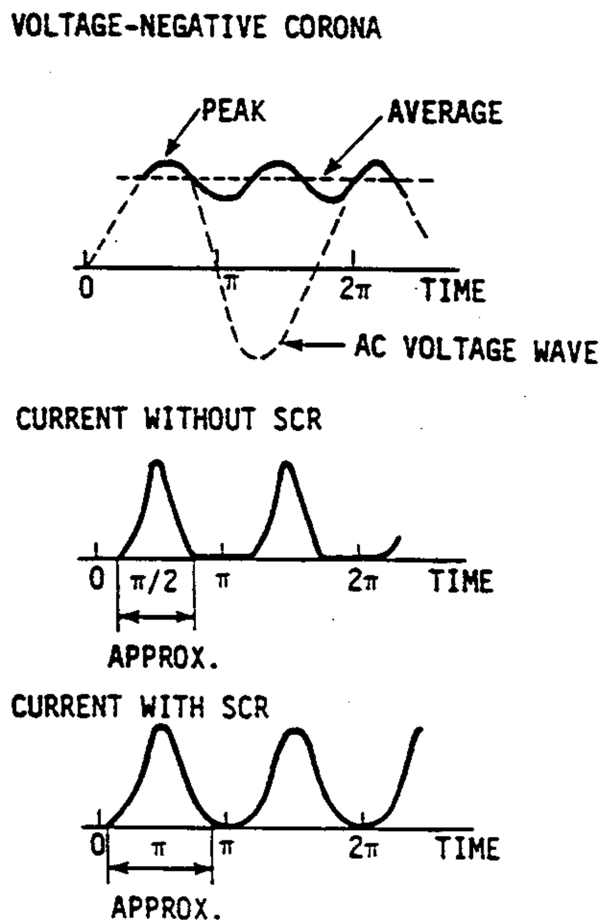


Figure 306.10 ESP Current Wave Form With and Without SCRs [7]

condition may arise. This condition does not necessarily indicate that the unit is underpowered, since it may have sufficient power to provide charging and electric fields without sparking.

Voltage-Limit Control

The voltage-limit unit of the automatic control module limits the primary voltage of the high-voltage transformer to its rated value. A potential transformer across the primary circuit supplies a voltage signal that is compared with a preset voltage value. The voltage control is set at the primary voltage rating of the high-voltage transformer. Primary voltage above this value generates a signal that retards the firing pulse of the firing module and brings the primary voltage back to the control setting.

Current-Limit Control

For current-limit control, a current transformer in the primary circuit of the high-voltage transformer monitors the primary current. The voltage from this current transformer is compared with the setting of the current control, which corresponds to the rating of the transformer-rectifier (T-R) unit. Any primary current that exceeds the unit's rating generates a signal that retards the firing pulse of the firing circuit (as with spark control) and reduces the current to the current-limit setting.

With all three control functions properly adjusted, the control unit energizes the precipitator at its optimum or maximum level at all times. This level is determined by conditions within the precipitator and results in one of the three automatic control functions operating at its maximum, i.e., primary voltage, *primary current, or spark rate.* When one of the three maximums is reached, the automatic control prevents any increase in power to reach a second maximum. If changes within the precipitator so require, the automatic control will switch from the maximum limit of one function to that of another.

The system also includes secondary overload circuits and an undervoltage trip device that operates when voltage on the primary of the high-voltage transformer falls below a predetermined level and remains below that level for a period of time. Another device provides a delay period in the annunciator circuit while the network of contacts is changing position to stabilize the circuit in response to undervoltage.

The electrical equipment ratings must be properly matched with load requirements. Over a wide range of gas temperatures and pressures in different applications, practical operating voltages range from 15 to 80 kv_{av} at average corona current densities of about 10 mA/1000 ft ^{2} to 300 mA/1000 ft ^{2} (100 to 3200 mA/1000 m ^{2}) of collecting area.

The following are some of the problems that can occur when power supply and load are mismatched:

1. The ESP is underpowered because of too few electrical sets, sets of wrong capacity, or too much collecting area energized from a single set.

2. Reduction of operating voltage with gas temperature, as shown in figure 306.11, can result from failure to fully evaluate effects of gas density and temperature on required operating levels. While voltage goes down, the current demands go up. At high pressures the reverse can occur.

3. A rectifier set larger than is required for the application, as when 1500 mA saturable reactor sets are operating on high resistivity ash at perhaps 100 mA, can lead to loss of control, excessive sparking, and poor efficiency.

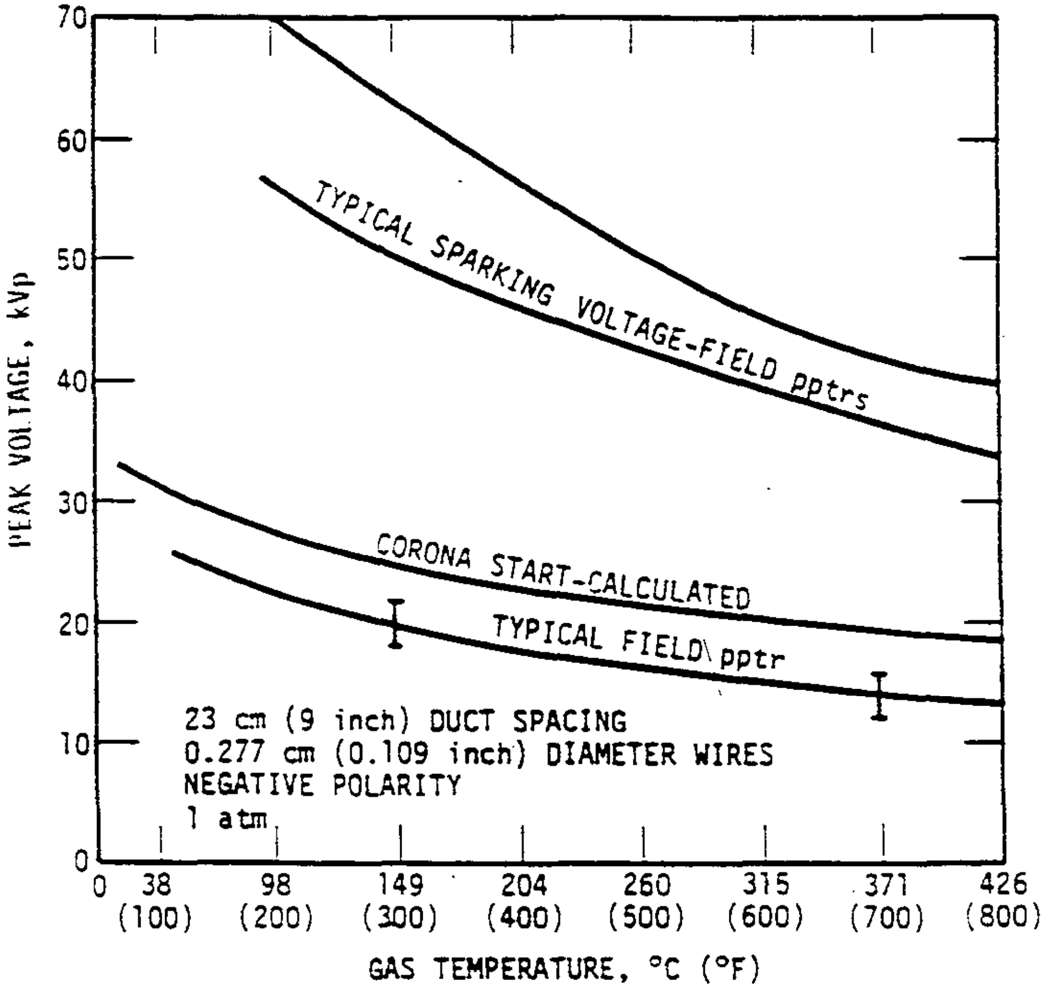


Figure 306.11 Typical ESP Operating Voltage vs. Gas Temperature [15]

307 INSTRUMENTATION

Electrostatic precipitator instrumentation consists mainly of monitors for power input, gas flow, rapper intensity, and hopper dust levels. The power input parameters are precipitator current, voltage, and spark rate. Gas flow parameters are the input gas flow rate and input gas temperature.

Locations

The ESP instruments are generally located in close vicinity of the ESP unit; when a plant has more than one ESP, a centrally located control room houses the instrumentation for all the ESP units. The location of the ESP control room depends upon the availability of space at the plant; however, it is generally located close to ESP units. Two common control room locations are on top of the ESP units, and directly under the ESP unit for an elevated unit. The ESP control room is typically located separately from the plant control room and near to the ESP to avoid long cable runs from the ESP to the plant control room.

Spark Rate

Opacity

An ESP instrumentation block diagram is shown in figure 307.1. Figure 307.2 shows the positions of various measuring instruments in the ESP circuit. The ESP in figure 307.1 has four transformer-rectifier (T-R) sets, and each T-R set has two bus sections. Primary voltage and primary current are measured for each T-R set; secondary voltage, secondary current, and spark rate are measured for each bus section. Gas flow rate and temperature are measured at the ESP inlet. An opacity measurement at the ESP outlet roughly indicates emission levels.

The ESP shown in figure 307.1 has four primary voltage meters (voltmeters) and four primary current meters (ammeters). The secondary side instrumentation consists of eight secondary voltmeters, eight secondary ammeters, and eight spark rate meters. The instrumentation schemes for different ESP installations may vary slightly from the basic scheme shown in figure 307.1.

The relative location of each instrument in the circuit is decided by its function. The primary ammeter, for example, is always located ahead of the transformer primary in order to indicate the current available for transformation. The inspector should understand the various positions of various ESP instruments. The function of each ESP instrument is discussed in the following paragraphs.

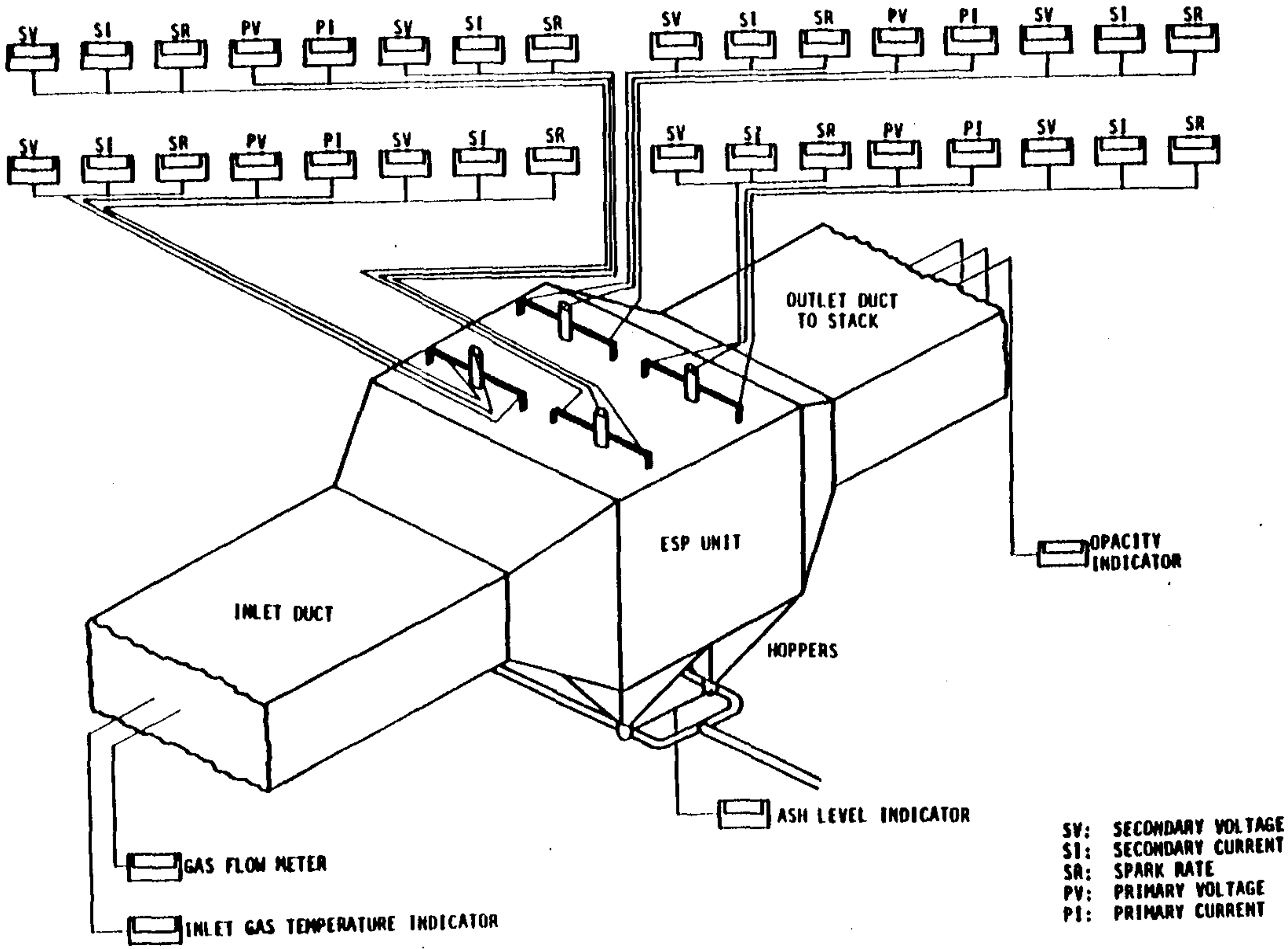


Figure 307.1 ESP Instrumentation Diagram [7]

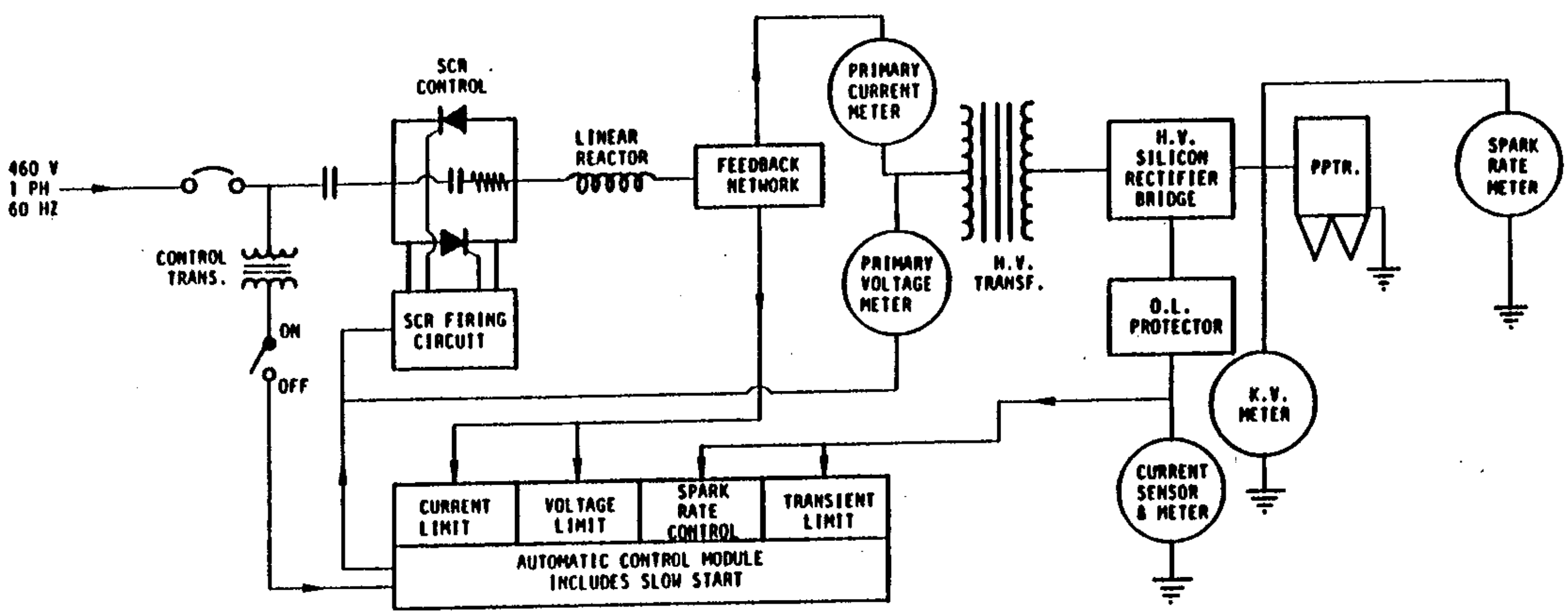


Figure 307.2 Positions of Measuring Instruments [16]

307.1 PRIMARY VOLTMETER

Energization power for an ESP is supplied at the primary side of the transformer-rectifier (T-R) set. The AC electrical power is normally supplied at 220 or 460 volts. Each T-R set for an ESP is normally provided with a voltmeter and an ammeter to indicate input voltage and input current.

The range of a voltmeter dial for primary voltage is 0 to 480 volts. Normal operating voltage is around either 220 or 460 volts, depending on the selection of supply voltage. A temporary marginal deviation of about 5 percent from the rated supply voltage is common and should not be considered a major operating problem. Generally, a label on the primary voltmeter indicates the maximum permissible voltage reading.

The voltmeter on the primary side is located ahead of the T-R set but after the power control circuit, linear reactor, and feedback network. This positioning of the voltmeter ensures measurement of regulated voltage available at the T-R set for transformation.

An indication of no voltage on the primary side may be due to an open primary circuit. The circuit breaker may be open or tripped, or the reactor secondary may be open. The open circuit breaker can be closed with power on, but replacement of the reactor secondary requires power switchoff and ESP shutdown.

An indication of high voltage on the primary could result from an open transformer primary or improper connection of an ESP. A faulty, open, or disconnected precipitator, an open bus, or a faulty rectifier will cause indication of high primary voltage. An ESP shutdown is mandatory for correcting these faults.

An indication of low voltage in the primary side could result from several conditions, such as a leak in the high-voltage insulation, high dust level in the hoppers, excessive dust on the electrodes, or swinging electrodes. Correction of the fault may require shutdown.

307.2 PRIMARY AMMETER

The ammeter on the primary side indicates the current drawn by the ESP. The current and voltage readings on the primary indicate the power input to a particular section of an ESP.

An ammeter for primary current measurement is located between the T-R set and the power control circuit, linear reactor, and feedback network. Figure 307.2 indicates the location of an ammeter for primary current. Positioning the ammeter between the T-R set and the control circuit ensures measurement of the current available for transformation.

The ammeter is generally labeled to indicate the normal range of primary current. Any deviation from this range indicates abnormal operation of the following ESP section. A reading that shows no primary current associated with no primary voltage indicates an open primary circuit, which may be due to open circuit breakers or an open reactor secondary. Minimal primary current associated with high primary voltage is generally caused by an open transformer primary or open secondary circuit. Precipitator shutdown is mandatory to correct these faults. Indication of low primary current with low primary voltage results from an open DC reactor. Again, precipitator shutdown is mandatory.

Additional descriptions of variations in both primary and secondary currents and voltages are given in section 500 (Troubleshooting) of this manual. Possible causes and conditions existing within the ESP are stated alongside these descriptions.

307.3 SECONDARY VOLTMETER

The secondary voltmeter is calibrated in kilovolts to measure the high voltage of the power input to the discharge electrodes. The secondary voltmeter is labeled to indicate the upper limit and normal range of the operative voltage.

The secondary voltmeter is located between the rectifier output side and discharge electrodes to indicate the DC voltage across the discharge electrodes.

An indication of no voltage on the secondary may be due to an open primary circuit. The circuit breaker may be open or tripped, or a reactor secondary may be open. As indicated earlier, the circuit breaker can be closed with power on, but replacement of a reactor secondary will require power shutoff and ESP shutdown. A faulty, open, or disconnected precipitator, an open bus, or a faulty rectifier will indicate high voltage on the primary side and no voltage on the secondary side. Shutdown of the ESP is mandatory for correcting these faults.

As stated earlier, additional descriptions of variations in both primary and secondary currents and voltages are given in the Troubleshooting section of this manual. Possible causes and conditions existing within the ESP are stated alongside these descriptions.

307.4 SECONDARY AMMETER

The ammeter on the secondary side indicates the current being supplied to the discharge electrodes. The combination of current and voltage readings on the secondary side indicates the power input to the discharge electrodes. The location of the secondary ammeter is as shown in figure 307.2.

The secondary current is stepped down in the transformer and is measured in milliamperes. The secondary ammeter is therefore calibrated in milliamperes and is labeled to indicate the maximum value and normal range of secondary current. Deviation from the normal operating range indicates improper conditioning in the precipitator.

A combination of no secondary current with no secondary voltage indicates an open primary circuit. Minimal secondary current associated with high voltage is generally due to an open transformer primary or an open secondary circuit. Precipitator shutdown is mandatory to correct these faults. An open direct current (DC) reactor will cause a low current flow and low voltage in the circuit.

307.5 SPARK RATE METER

The spark rate meter on an ESP is a major indicator of its performance. The spark rate meter is generally connected in the secondary circuit; it indicates the number of sparks in the precipitator section and is calibrated in number of electrical sparks per minute.

The number of sparks together with secondary voltage and secondary current give a fair representation of the ESP operating condition. Theoretically, the power input to a section is maximum when no sparks occur and voltage and currents are at their rated maximum; in actual practice, however, the optimum power input occurs at a preset spark rate. Optimum spark rate depends on the physical and design characteristics of the ESP.

Because excessive sparking indicates power loss, less power is available for particle charging. A sparking rate below the optimum level indicates a power supply below optimum.

307.6 INLET GAS FLOW AND TEMPERATURE

The gas flow rate and temperature are indicators of ESP loading. Any variations from the normal design ranges will affect ESP performance and should be investigated. At most installations, the gas flow and temperature measurements are taken at the exit of the process unit or boiler. The instruments for recording the flow and temperature are generally located in the main control room. Some installations maintain continuous records of gas flow and temperature.

307.7 OPACITY AT ESP OUTLET

A general configuration of the opacity monitoring system is shown in figure 307.3. The system includes an opacity detector unit that senses the opacity of gases passing through the ductwork. This unit includes a light source and a detector. The difference between the amount of light transmitted by the light source and that received by the detector indicates the particulate concentration in the gases. The difference is calibrated as percent by the opacity meter. An opacity reading of zero represents a minimal particulate concentration.

Strip Chart Recorder

An electronic strip chart-recorder continuously records opacity values. Many models zero themselves automatically at regular intervals; this adjustment is indicated on the chart paper.

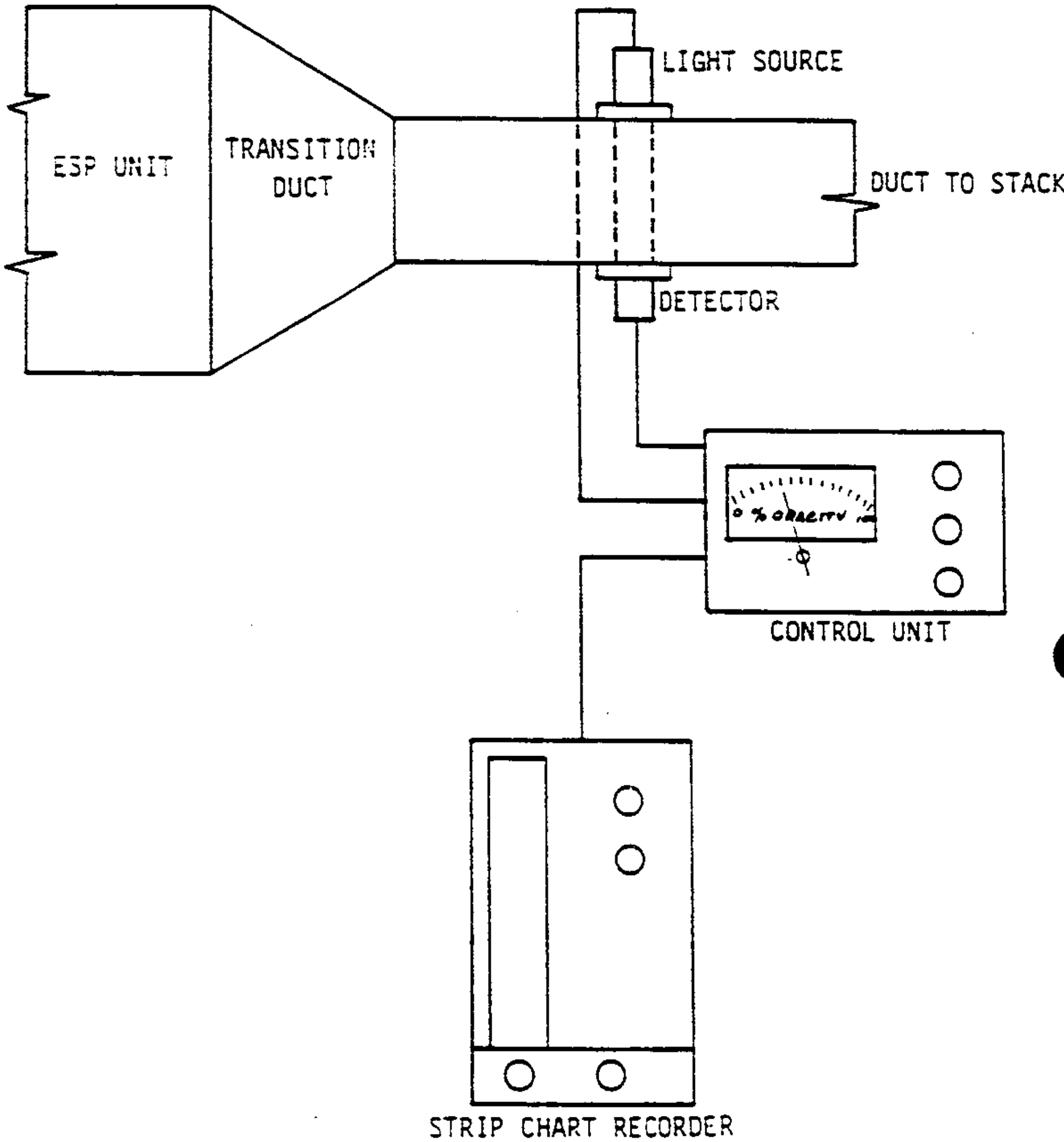


Figure 307.3 Connection Diagram of the Opacity Monitoring System

307.8 ASH DISCHARGE

Efficient removal of ash from the hoppers is important for proper ESP performance. Ash removal systems at ESP installations are generally equipped with instrumentation that indicates emptying of the hoppers and continuously records the vacuum in the system.

Hopper Alarms

Hopper level alarms are another common and useful type of instrument. Level detectors can utilize gamma radiation, sound capacitance, pressure differential, or temperature. The alarms should be located so that filling of hoppers does not occur, but frequent alarms are avoided. A low temperature probe and alarm can be used in conjunction with the level detector. Control panel lights are used to indicate the operation of hopper heaters and vibrators. Automatic phase-back of T-R sets in conjunction with full hopper level alarms are also incorporated into the instrumentation of some ESP designs.

In general, although various vendors provide different ash discharge systems, the instrumentation and records are similar. Zero motion switches are used on rotary air lock valves to detect malfunction, as well as on screw conveyors. Pressure switches and alarms are normally used with pneumatic dust handling systems to detect operating problems.

307.9 RAPPERS/VIBRATORS

Microprocessor type technology is available for a high degree of rapper control flexibility and ease of maintenance. For example, in order to prevent control damage from ground faults, new controls will test each circuit before energizing it. If a ground fault occurs, the control will automatically bypass the grounded circuit and indicate the problem on an light emitting display (LED), thus permitting fast location and solution of the problem.

Instrumentation should be used in conjunction with a transmissometer to help in troubleshooting ESP problems. Separate rapping instrumentation should be provided for each field. Readings of frequency, intensity, and cycle time can be used with T-R set controls to properly set rapper frequency and intensity, in the case of weighted-wire discharge electrodes.

For rigid frame mechanical rappers, cycle time and rap frequency of both internal and external types are easy to measure. Individual operation of internal rappers is not easily instrumented, nor is intensity control possible without a shutdown of the ESP.

400 INSPECTIONS

Air pollution control district inspectors inspect electrostatic precipitators (ESPs) on a regular basis. ESP operators must do the same, as part of a formal maintenance program, in order to ensure that their units are operating at design or near-design efficiencies. This chapter is written for both audiences.

Safety procedures to be observed when planning on entering an ESP are outlined in section 605 of the Maintenance chapter.

Sample inspection checklists are found in appendix C.

401 PRE-INSPECTION

A logical starting point for regulatory inspectors in the inspection process is to review the files concerning the specific plant. Construction and operating permits and pending compliance schedules pertaining to source processes should be pulled and studied. The inspector should also obtain copies of breakdown records and any reports about past noncompliance, so as to know the frequency of various malfunctions reported, the history of abnormal operations (including operation while under variance), and past conditions and causes of noncompliance.

Baseline

The inspector should prepare a concise file containing basic plant information, process descriptions, flowsheets, and acceptable operating conditions. It should contain the following to facilitate inspections and/or preparations:

1 A chronology of control actions, inspections, and the complaints concerning each major source in the plant;

2 A flowsheet identifying sources, control devices, monitors, and other information of interest;

3 The most recent permits for each major source;

4 Previous inspection checklists;

5 A set of process operating conditions, fan characteristics, and raw material characteristics;

6 A set of general arrangement drawings of the control equipment, ventilation system layout, and waste handling system.

The inspector should select a time to inspect the plant such that the processes will be operating at representative conditions. This is especially important in the case of operations with seasonal schedules.

401.1 INSPECTOR EQUIPMENT

The following tools and safety gear should be carried in a portable case from source to source. The inspector should have these available at all times.

Hardhat
Safety glasses or goggles
Gloves
Coveralls
Steel tipped safety shoes
Ear protectors
Tape measure
Flashlight
Manometer or differential pressure gauge
Stopwatch
pH paper
Duct tape
Pry bar
Pocket calculator
Pocket guide of industrial hazards
Polaroid camera
Compass

The following pieces of equipment can be left in a central location until needed:

Respirator with appropriate cartridge
Velometer
Pump and filter system
Bucket
Combustion gas analyzer
Thermometers or thermocouples

Multimeter
Sample bottles
Strobe
Inductance ammeter
Tachometer
Oxygen and combustibles meter
Self-contained breathing equipment
Pipe wrench
Rope

Safety

Particularly important is the safety equipment. It is the inspector's responsibility to have safety equipment before entering the plant. Access to certain industrial facilities can be rightfully restricted or refused by plant representatives if designated equipment is not worn.

400 INSPECTIONS

402 PRE-INSPECTION INTERVIEW

The inspector should discuss the purpose of the inspection with the appropriate plant official. Any changes in plant management should be noted. The inspector should ask questions relating to the process and the ESP to determine whether information from the file on the facility still pertains. Listed below are questions an inspector might ask about process operational changes and changes in ESP operation.

1 Has the rate of production increased or decreased?

2 Has there been a change in the product mix? (For example, in a cement plant, this would include a change in the moisture content of the slurry.)

3 Have operating temperatures changed? (This can result from the addition of energy conservation retrofits. Examples are the addition of economizers to a boiler, the addition of air or raw material preheaters in a molten metal process, or the addition of more chains in a kiln in a cement process.)

4 Have there been changes in startup or shutdown procedures?

5 Have there been any changes such as the addition of new forced-draft fans or new induced-draft fans? Any addition or removal of afterburners?

6 Has there been any change made in the use of collected dust in the process, such as reinjection or return of the dust to the raw material mix?

7 Has the amount of excess air been changed? Has the soot blowing schedule been revised?

8 Has the effective size of the dust collector been changed? (ESP fields out of service, or new fields added.)

9 Have power input levels to the dust collector been increased/decreased? (Additional power supplies, new ESP power controls, additional reactors, power factor or rectification revisions.)

10 Have new sources of emissions been added to the ESP (such as vents from tanks in a paper mill)?

11 Have any retrofits been added or removed in the ESP system? (Examples are gas conditioning, sectionalization of power, additional or more powerful rappers, power off rapping, new rapping sequence controls, new power controller systems, etc.)

12 Have there been any changes in the dust removal system, power off rapping, new dust conveying equipment or arrangement of dust conveyors, vacuum/pressure system changes, evacuation sequence changes, combination or isolation of dust removal sytstems from several units?

Table 402.1
Baseline Test Information

Process Conditions	Gas flowrate Gas temperature - point A, B, C, etc. Static pressure Process level (load, % capacity) Process feed rate(s) Process feed descriptor(s) Process product level(s) Process product descriptor(s)
ESP Operating Conditions	Gas temperature, ESP inlet(s) Gas temperature, ESP outlet(s) Primary voltage Primary current Secondary voltage per T-R set for each field Secondary current per T-R set for each field Spark rate Rapper frequency, plate Rapper frequency, wire Rapper duration, plate Rapper duration, wire } per field for each T-R set

403 COUNTERFLOW INSPECTION

The "Counterflow" inspection procedure described here was developed by PEDCo Environmental, Inc. (PEI), to aid both source operators and regulatory agency inspectors in routinely evaluating performance of air pollution control equipment. The Counterflow technique allows an inspector to rapidly identify significant changes in performance and the possible reasons for these changes. It does not necessarily provide definite evidence of noncompliance, nor does it necessarily provide a specific list of repairs required.

Baseline

Sets of Data

The fundamental principle of the Counterflow technique is simply that performance diagnosis is done by comparison of observed operating conditions with a site specific baseline operating condition. Another basic principle is that field measurements may be subject to error, or may be impossible to make. Diagnosis of problems is therefore based on information from sets of data rather than on just one parameter. Table 403.1 lists baseline test information that the inspector should have on hand.

The Counterflow inspection technique is so named because it begins at the gas exhaust point, and proceeds in a direction counter to the process flow to the point where the raw materials are input. This is designed to minimize inspection time and reporting requirements, and to maximize the amount of useful information obtained. By using the counterflow direction, the information gathered first is not only easily obtained, but is also useful in either narrowing the scope of the inspection or even in terminating it if all is deemed well.
The baseline operating conditions are determined by proper stack test measurements of the plant's emissions. Reference Method 9 opacity readings made at the same time should be compared with the stack test results. This enables the inspector to determine the relationship between the mass standard and the opacity standard for the source to be inspected.

Comparison of opacity and stack test results with the regulatory standards enables the inspector to determine the margin of safety with which a plant is operating in baseline conditions. If the margin is slim, a small change in ESP performance or a slight process variation may result in a violation. If the baseline emissions are well below the allowable standard, major changes in operation or severe deterioration of ESP performance are needed to result in noncompliance. The inspector must always be cognizant of this compliance margin.

400 INSPECTIONS

The Counterflow inspection technique can be divided into nine inspection steps. These are:

1 Observe the stack effluent
2 Check the continuous monitors
3 Measure the fan operating parameters
4 Analyze ESP performance
5 Perform an external inspection of the ESP
6 Evaluate ash handling procedures
7 Evaluate process operating conditions
8 Perform an internal inspection of the ESP
9 Review operating records

These steps are arranged in such a way that an inspector would have enough information at the end of step 3 to determine whether or not the stack effluent rate is in compliance with air pollution regulations. If this is so determined, the inspector may skip over steps 4 through 8. If compliance is either not yet shown, or if it is in doubt, the inspector should move on to step 4. In fact, only in rare cases will an inspector ever perform an internal inspection of an ESP.

Details for the inspection steps are given in sections 403.1 through 403.9.

403.1 OBSERVE THE STACK EFFLUENT

Opacity readings of emission points should be made using Method 9 procedures. Opacity readings can be used for more than determining the compliance status of the effluent with the opacity standards. They can also be used to diagnose changes in system performance. This is described in the following paragraphs.

In most cases, there is a relationship between the opacity observed during the inspection and the mass emissions penetrating the control device. Regardless of the mathematical form of this relationship, as opacity increases, the mass emissions generally increase.

In figure 403.1, Case 1 represents the most sensitive relationship--a small increase in opacity indicates a large increase in mass emissions. However, errors inherent in a small opacity increase can make any conclusions meaningless in this case.

Opacity vs. Mass Emissions

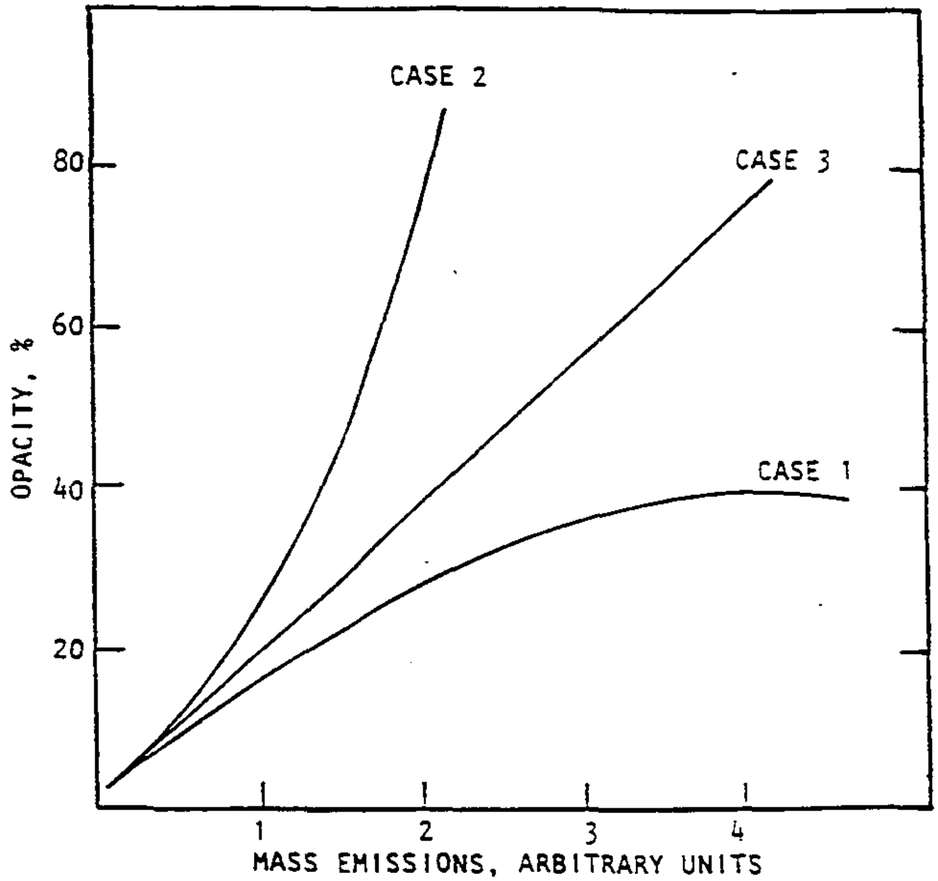


Figure 403.1 Opacity-Mass Relationships [17]

Case 2 presents "contrary" problems--above a certain upper opacity level, there is no change in upper opacity rates. At this level, opacity has no diagnostic value. The ideal case is the linear relationship of Case 3, which is generally the prevailing relationship in most industries.

Mass emission regulatory limits and opacity limits may not always agree. Linear relationships in figure 403.2 illustrate these possible disagreements. Case 4 represents the intended situation, where any violation of an opacity regulation also involves a violation of the mass emission regulation. In Case 5 there is a substantial opacity violation without a violation of the mass standard. In other cases (represented by line segment 6), a violation of mass emission standards might not be suspected due to decreased sensitivity to opacity. The point is that in certain cases, the absolute magnitude of the observed opacity is most useful when the opacity-mass relationship is known.

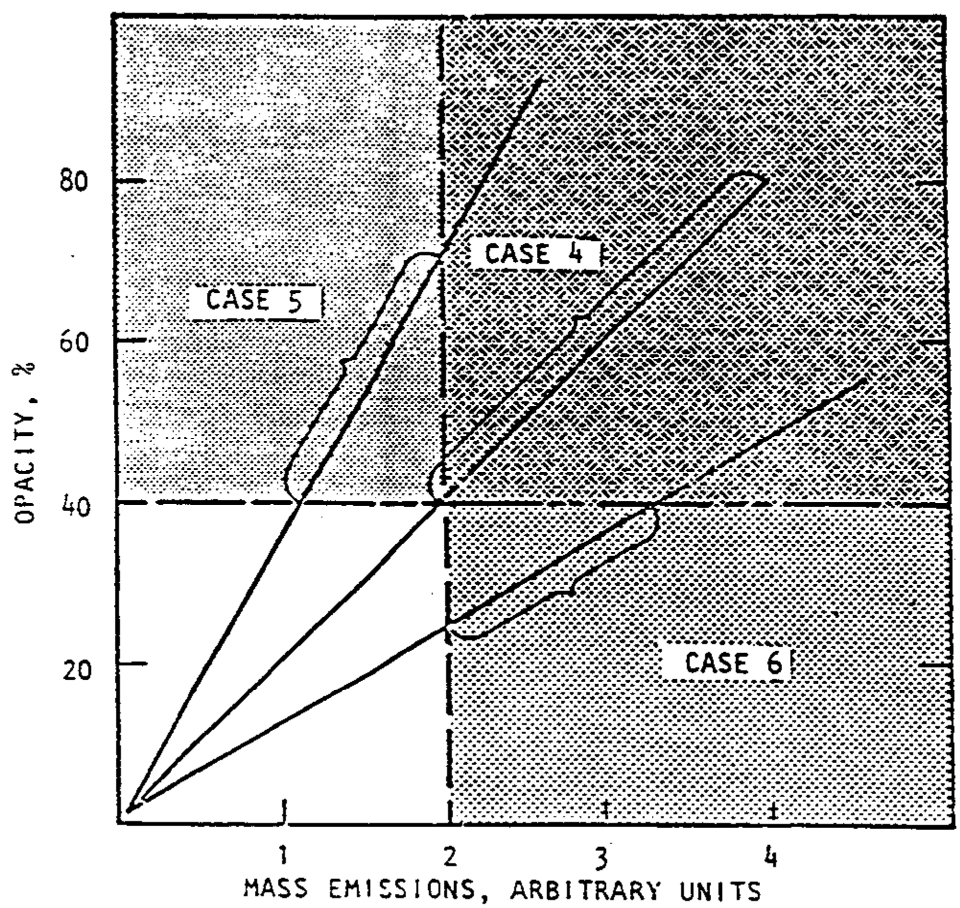


Figure 403.2 Opacity and Mass Emission Violations [17]

400 INSPECTIONS

In the diagnostic phase of the Counterflow approach, the procedure uses (whenever possible) a change in opacity, observed vs. historical, rather than an absolute magnitude of observed opacity. Regardless of the opacity-mass relationship, a change in opacity does indicate a change in mass emissions.

Plume Color

The color of the effluent is another plume characteristic which should be observed. For fossil fuel combustion sources, the color is an indirect indication of operating conditions. Table 403.1 shows causes for various colors of plumes.

For other types of sources, the color may not be as variable or may not have a distinct meaning with respect to the process or the control equipment. Nevertheless, a change in the color indicates a change in the system. For example:

1 Increased quantities of bluish particulates generally indicate increased generation of very small particles (0.1 to 2 microns) which are difficult to collect in most control devices.

Vapors

2 A detatched plume demonstrates fairly conclusively that particulates are forming as the vapors are released to the cold ambient air. Detatched plumes often cause serious corrosion problems, since any cold surface in the system is susceptible to acid-mist condensation.

Puffs

3 Frequently occurring, short duration "puffs" from the stack are often caused by rapping reentrainment problems in ESPs. Cyclic process conditions can also lead to puffs.

Table 403.1
Plume Characteristics and Combustion Parameters

Plume Color	Possible Operating Parameters to Investigate
White	Excess combustion air; loss of burner flame in oil-fired furnace
Grey	Inadequate air supply or distribution
Black	Lack of air; clogged or dirty burners or insuffficient atomizing pressure,improper oil preheat
Reddish brown	Excess furnace temperatures or excess air; burner configuration
Bluish white	High sulfur content in fuel

403.2 STEP 2: CHECK THE CONTINUOUS MONITORS

After observation of the stack effluent, the next step is to check the continuous monitors (transmissometers) downstream from the control equipment. This involves:

1 Checking the operation of the purge air blowers and the alignment of the source and retro-reflection;

2 Comparing the actual path length with the value used in the instrument calibration;

3 Checking the zero and full scale settings without taking the instrument offline, if possible;

4 Checking the status of the window inductor light;

5 Studying the instrument recording trace with a view to changes in recorded values, which may indicate that the transmissometer is operating unreliably.

Process operating personnel should be able to provide information on the technique and the frequency of calibrations.

Confirm Opacity Observations

The transmissometer data should be able to confirm and clarify the opacity *observations in step 1. Instrument problems should be suspected when there are* substantial differences between the opacity recorded in step 1 and that indicated on the monitor. If the instrument response time and the recorder chart speed have been set properly, it will be possible to check for trends in the opacity levels.

A cyclic pattern suggests variation in process operating conditions.

A continually deteriorating pattern suggests a developing problem in the ESP, which is likely to demand the attention of the inspector. A deterioration can also suggest, on the other hand, a gradual drift of the instrument or accumulation of dirt on the optical surfaces.

Spikes

Intermittent emission spikes may represent emission caused by either rapping reentrainment or by soot blowers.

Failure to operate and/or maintain an opacity monitor can constitute a violation of regulations.

In step 2, the inspector should have:

1 Confirmed the visible emissions status with respect to opacity regulations;

2 Confirmed the installation and operating status with respect to continuous monitor regulations;

3 Developed a preliminary idea of the process and the ESP operating conditions.

As yet, there would not be enough information to evaluate mass emissions in cases where a reliable opacity-mass emission correlation has not been identified.

403.3 STEP 3: MEASURE THE FAN OPERATING PARAMETERS

Three operating parameters of the induced draft fan are useful in interpreting control system operations. They are:

1 Increase in total static pressure across the fan;

2 Electrical current drawn by the fan motor;

3 Revolutions per minute (rpm) of the fan wheel.

Gas Flowrate

Evaluated together, these parameters indicate the gas flow rate and the total system pressure drop. These changes are important in diagnosing control system operating conditions. If the inspector has performance curves for the fan, he can use these parameters to find the gas flow rate through the fan from the fan curves. However, even without the fan charts, the inspector can use the above three parameters by comparing the measured values with the baseline values.

If the fan parameters are not monitored at the plant, the inspector should use an inductance ammeter to measure motor current, a manometer (or magnehelic gauge) to measure fan static pressure, and a tachometer (or a strobe in cases where the tachometer cannot be used) to measure fan speed. The inspector should request that static pressure taps be made in the ductwork leading to and from the induced draft fan. The inspector should not drill or cut these holes unless the plant manager approves. Once taps are available, the static pressure at the fan inlet and outlet should be measured using the set of magnehelic gauges.

At the end of step 3, the inspector should decide whether or not further on-site efforts are necessary to determine compliance with mass emission standards. If the fan operating parameters (static pressure, motor current, and rpm) are within plus or minus 10 percent of baseline values and if the gas temperature at the fan inlet is within 20 °F, it is unlikely that mass emissions have changed significantly. Generally, it is necessary to inspect the control equipment (step 4) to confirm the evaluations of steps 1, 2, and 3.

Air Inleakage

A second purpose of the fan inspection is to determine if serious air inleakage is occurring and if this is compromising pollutant capture efficiency back at the source. This problem is confirmed by measuring flue gas oxygen levels at the fan inlet. Reduced gas temperature and increased fan current further support air inleakage checks.

403.4 STEP 4: GAUGING ESP PERFORMANCE FROM ELECTRICAL DATA

The control sets for the ESP are usually located either on top of the ESP, or in a room remote from the ESP. Plant personnel should provide a diagram showing which fields are served by which T-R sets, as a guide to determining out-of-service fields when reading the T-R set gauges.

Drift

Control panels can include primary and secondary current and voltage meters, and a spark rate meter. The voltage, current, and spark rate should be recorded for each section. The control set readings should be compared with calibrated or design values for each bus section. The inspector should check the daily log of control readings to determine whether the readings have been drifting from normal. Drift is indicative of such problems as air inleakage at air heaters or in ducts leading to the ESP, dust buildup on ESP internals, and/or deterioration of electronic control components.

The inspector should also make note of inoperative meters, the number of power supplies on "manual" control, and T-R sets on "auto" that are held to operating levels below design specifications (such as might be done to reduce wire breakage).

Performance evaluation in this step should include, but not be limited to:

1 Power density calculations
2 Evaluation of parallel field secondary currents
3 Evaluation of inlet field secondary currents
4 Evaluation of spark rate

Problem areas occurring in the ESP produce tell-tale symptoms in the electrical set data. There are four problem areas in which the performance of an ESP can be affected. These problem categories, and examples of such problems are:

1 Electrical -- power input, excessive sparking;
2 Gas flow -- flow rate, temperature and grain loading changes, air inleakage;
3 Mechanical -- hopper overflow, broken discharge wires, misalignment, rapper and insulator failure;
4 Effluent -- resistivity and particle size changes.

Symptoms

In each problem category, there are three to five symptoms which occur with reasonable frequency, but the observed symptoms do not often indicate a particular problem. Due to the complexity caused by the interfacing of these problems, it is important that the inspector use a combination of symptoms in identifying operational difficulties.

Mechanical problems generally result in a reduced operating voltage. The large majority of internal problems result in increased currents. This is often the result of sparking which occurs due to close clearances or due to the current which passes through a high resistance short. An internal problem which does not result in increased currents is failure of the collection plate rappers. In the case of rapper failure, the gradual increase in the dust layers results in a relatively rapid decrease in the secondary currents.

400 INSPECTIONS

The spark rate in a field with internal problems is generally higher than the baseline level if the condition results in a reduced space between the collection plate and the discharge electrode system.

Two common problems which do not result in higher spark rates are insulator tracking and high resistance shorts. In these cases, the voltage will be lower and the currents will be higher, but the spark rates will usually be unchanged.

Resistivity problems may be further indicated by a change in gas temperature and by a decrease in the fuel sulfur content.

Additional data is necessary to narrow down the list of potential problems which could be actually causing the shift in electrical set data. For example, excessive air inleakage noted in Step 3 may contribute to electrode misalignment and cause sparking in localized areas, resulting in reduced primary voltages.

General examples of the effect of changing conditions in the gas stream and within the ESP on control set meters are presented below:

1 When the gas temperature increases, the voltage will increase, and the current will decrease. Sparking can develop. When the gas temperature decreases, the voltage will decrease, and the current will increase;

2 When the moisture content of the gases increases for any given condition, the current and voltage will also tend to increase in value;

3 If reduced voltage exists because of a sparkover, a rise in moisture may allow for an increase in the precipitator voltage level;

4 An increase in the concentration of the particulate will tend to elevate voltages and reduce current flow;

5 A decrease in the particle size will tend to raise voltage while suppressing current flow;

6 An increase in particulate resistivity will tend to increase voltage levels in all bus sections, and reduce current flow in all bus sections.

7 A higher gas velocity through the precipitator will tend to raise voltages and depress currents;

8 Air inleakage may cause sparkover in localized areas resulting in reduced voltages;

9 A number of precipitator fields in series will show varying readings with voltage to current ratio decreasing in the direction of gas flow;

10 If a hopper fills with dust causing a short, the voltage will be drastically reduced, and the current will increase;

11 Misalignment of collection plates will show as lowered voltage levels, and high current levels.

12 If a discharge electrode breaks, violent arcing can be observed with the meter readings swinging between zero and normal;

13 If a T-R unit shorts, voltage will be zero at a high current reading;

14 If a discharge system rapper fails, the discharge wires build up with dust; the voltage increases to maintain the same current level;

15 If a plate rapper fails, the voltage decreases to maintain a current level under sparking conditions;

Table 403.2 presents specific examples of the effect of changing conditions within the ESP on the control set readings. These examples are typical of what the inspector could expect to find. The inspector should become familiar with these meter reading techniques, so as to be able to recognize problems during an inspection.

Corona power readings can also be used to estimate operating efficiency of the ESP; this is discussed in more detail in section 403.4.1.

Identify Fields With Problems

Fields showing significant deviations from baseline conditions are to be targeted for more intensive inspection. However, if no major problems are apparent from the electrical set data and there are no observations of changes in effluent characteristics (increased gas flow rates, smaller particle size distribution, higher temperatures), then the regulatory inspection should be terminated. Inspections conducted by source personnel should generally continue regardless of the initial results since operators are generally more interested in identifying problems which may not yet have disrupted performance.

Table 403.2 Example of Effects of Changes in Normal Operation on ESP Control Set Readings [18]

Condition	Effect	Primary Voltage V, AC	Primary Current A, AC	Secondary Current mA, DC
Normal full load	- -	300	50	200
System load fall by 50 %	Gas volume and dust concentration decrease, resistance decreases	260	55	230
System load constant, but dust load increases.	Resistance increases	350	40	175
Gas temperature increases	Resistance rises, sparking increases because of increases resistivity	300 - 350	50 - 60	200 - 250
Gas temperature decreases	Resistance decreases	280	52	210
ESP hopper fills with dust	Resistance decreases	180	85	300
Discharge electrode breaks	Resistance may fall to 0 (may vary between 0 and normal of top part of electrode is left swinging inside the ESP). Violent instrument fluctuations. Arcing can be heard outside the ESP.	0 - 300	0 - 50	0 - 200
Transformer-rectifier shorts	No current passes from the T-R set to the ESP.	0	100 +	0
Discharge system rapper fails	Dust builds up on discharge electrodes. Resistance increases because corona discharge decreases. Additional voltage required to keep current constant.	330	50	200
Collection plate rapper fails	Sparking increases. Voltage must be reduced to keep current constant.	265	50	200

403.4.1 Corona Power Method Of Gauging Performance

Power-Emissions Relationship

Under certain conditions, the stack particulate emissions are inversely proportional to the power input to the ESP: the greater the power input, the lesser the stack particulate emissions. If used carefully, this relationship can provide a good method for determining if a shift in the electrical data has resulted in a significant increase in the mass emissions.

The inspector or source operator can, by performing a few calculations, form an estimate of the mass emission level from the ESP without performing a source test. The following paragraphs delineate the conditions for use of this method; the theory behind the corona power method; and sample calculations.

Criteria

Criteria necessary to use this relationship are:

1 Particulate resistivity is moderate to high

2 Power input level to ESP is less than 1000 watts per 1000 ACFM.

Power input data should be used for this purpose only when the apparent particulate resistivity is either moderate or high. Particulate resistivity is determined by observing the secondary current and spark rate trends in each chamber. Decreased secondary currents and voltages, and an increase in the spark rates in all fields of the chamber, indicate high resistivity. Low resistivity is characterized by increased secondary currents, decreased voltages, and decreased spark rates in all fields of the chamber.

Imprecise

It is important to emphasize that a precise relationship cannot be developed between the power input and ESP efficiency even when the resistivity is in the moderate or high range. The power input therefore cannot be used to determine compliance with the mass emission regulations. It is very useful, however, for determining if there has been a major increase in the emissions since the baseline period.

When the resistivity is low, the power input is not related to the efficiency ot the ESP. In fact, the power input can rise as the emissions increase.

Also, malfunctions may occur, such as high resistance shorts and wire-plate misalignment, where a field may experience an increase in power input while the effectiveness of the filed declines.

If secondary voltage meters are available on the precipitator, the power input for a field can be calculated simply by multiplying the secondary voltage (kilovolts) times the secondary current (milliamps), as shown in equation 403.1 below.

Secondary Values

Corona Power = [Secondary Voltage] x [Secondary Current]

The total for a chamber is the sum of the power inputs for the fields in that chamber. The reason for calculating power inputs by chambers instead of for the whole unit is that one electrically weak chamber can result in emissions well above the regulatory limit, even if the remainder of the precipitator is operating well.

The resulting number should then be divided by the gas flow rate or an indirect measure of gas flow rate (such as the boiler steam rate) to get the total power input per unit of gas flow rate. In the large majority of cases, the gas flow through a given chamber is not known. The steam rate of a boiler (or other product rate parameter in other applications) can be used as an indirect measure of gas flow by comparison with the baseline stack test. If there is more than one chamber in the unit, it will be necessary to assume equal gas distribution to each chamber.

If the secondary voltage meters are not available, the primary voltage meter and primary current meter readings should be used. The actual power seen by the corona is less than the power calculated off the primary side meters, because of losses related to the specific design of the power supply and the present operating conditions within the field. Calculations of this loss factor are very complex, and are not to be determined by either the operator or the inspector. The factor is usually selected arbitrarily from a range of 0.6 to 0.8. Once the factor is chosen, it should be used consistently for the unit. As is the case with secondary side meters, the sum of the power input to the chamber should be calculated and divided by some reasonable measure of the gas flow through the chamber.

For example, if a loss factor of 0.75 is selected, the equation for corona power would be:

Primary Values

[Primary Voltage] x [Primary Current] x 0.75 = Corona Power

The theoretical relationship between the power input and the penetration through the precipitator (mass emissions) is shown in the graph in figure 403.3 and in the following equation:

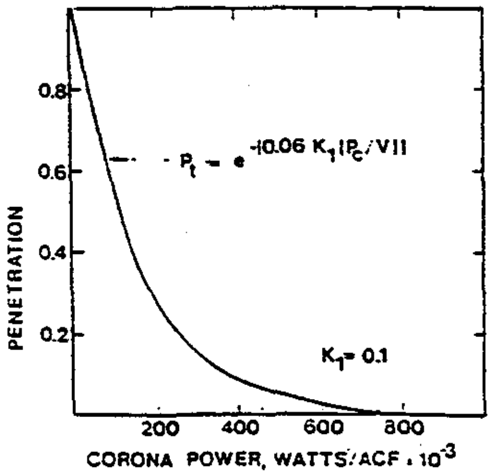


Figure 403.3 Penetration vs. Corona Power [18]

$P_t = e^{-(0.06\,[K_1]x[P_c/V])}$ Eqn. 403.2

This suggests a logarithmic relationship with the mass emissions decreasing as the power input per unit of gas flow increases. The term P_c/V is simply the power input of the chamber divided by the measure of the gas flow. The K_1 factor lumps together a number of important particle characteristics. Table 403.3 lists typical values of K_1 for different industrial categories. Unfortunately, the factors which make up the K_1 factor vary substantially from plant to plant, and even vary to some degree at a given plant. This is one of the fundamental reasons that the power input correlations are inadequate for determining compliance. Even if used carefully, these correlations can provide only a general index of a change in precipitator performance.

In figure 403.3, a K_1 value of 0.1 was chosen. Figure 403.4 illustrates the impact on penetration of selecting different values for K_1. Going from a K_1 value of 0.5 to 0.2 increases the penetration from 0.01 to 0.1. This corresponds to a decrease in efficiency from 99% to 90% at a given power input. In real life, the factors which influence the K_1 factor do not vary quite this much at a given plant.

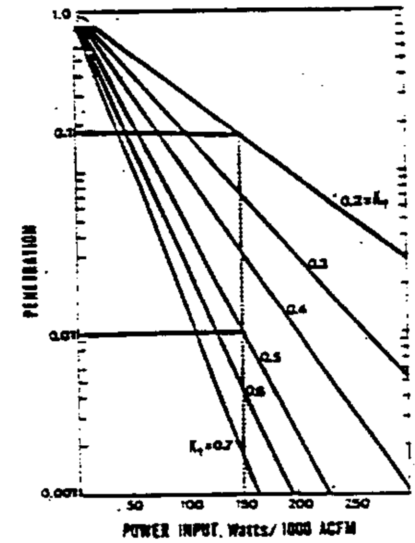


Figure 403.4 Penetration vs. Power Input for Different K_1 Values [19]

Table 403.3
Corona Power Emissions Coefficient K_1 For Several Industrial Categories

Industrial Category	K_1 Coefficient
Electrical utility fly ash	0.55
Pulp and paper	0.129
Recovery boiler	0.106
Cement plants (range with wet and dry process)	0.785 (wet) 0.226 (dry)
Municipal incinerators (range)	0.57 -- 1.88
Steel -- open hearth furnace	0.19

Figure 403.5 illustrates the typical shape of power input -- mass emissions (penetration) correlations.

At very low power inputs, the penetration does not go to 1.0 (0% efficiency) as suggested by equation 404.2. Due to particle settling, there is some removal even when the power is off.

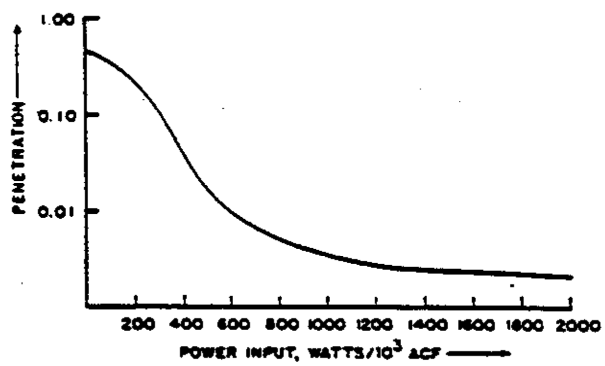


Figure 403.5 Typical Curve for Penetration vs. Power Input [19]

At very high power input levels (greater than 1000 watts per 1000 ACFM), the mass emission rates are not at all sensitive to the power input rates. Under these conditions, the emissions are determined by the extent of nonideal mechanical factors such as sneakage, rapping reentrainment, and other forms of reentrainment. Attention should be focused on the factors contributing to particulate loss.

Most ESPs fall into the range of 150 to 750 watts per 1000 ACFM, and in this range, the power input is a useful parameter.

The following example case will demonstrate the corona power method of evaluating ESP performance in a dry cement process, using data from table 403.4.

Table 403.4 presents abbreviated results from a stack test and an inspection performed at a later date. Notice that most of the operating data and conditions listed in table 403.4 are virtually the same for the stack test and the inspection.

Table 403.4
Example data from stack test and inspection results

	Stack Test Results	Data From Inspection
Production rate, MW net	640	640
Gas Temperature, oF	500	500
Total Corona Power, W	312,500	250,000
Gas Flow Rate, ACFM	1,250,000	1,250,000
Specific Corona Power, W/1000 ACFM	250	200
Particulate Emission Level, grains/ACF	0.022	?

The corona power readings, however, are at reduced levels at the time of the inspection. The following calculations will demonstrate a method of estimating the emission level during the inspection.

Use equation 403.2 and stack test results to determine penetration:

Penetration

$P_t = e^{-([0.06] \times [K_1] \times [P_c/V])}$

$= e^{-([0.06] \times [.226] \times [250])}$ where P_c/V = 250 watts/KACFM

$P_t = 0.0337$

Efficiency

Efficiency = 1 - Penetration

= 1 - 0.0337

Efficiency = 0.9663 = 96.63 %

Coefficient of Proportionality

Since penetration is proportional to emission level, the coefficient of proportionality can be calculated by:

$[P_t] \times [C] = E.L.$

where C = coefficient and E.L. = emission level

Emission Level

Rearranging to determine the coefficient value, and using stack test results for E.L. = 0.022 grains per ACF,

$C = [E.L.] / [P_t]$

$= [0.022] / [0.0337]$

$C = 0.6527$

Using equation 403.4 and the inspection data to determine penetration:

$P_t = e^{-([0.06] \times [.226] \times [200])}$

$P_t = 0.0664$

Efficiency = 93.36 %

Using the coefficient value from the stack test, and the calculated penetration value for the inspection period, calculate the estimated emission level by using:

$E.L. = [P_t] \times [C]$

$= [0.0664] \times [0.6527]$

E.L. = 0.0433 grains per ACF

The calculations indicate that the emission level practically doubles.

403.5 STEP 5: EXTERNAL INSPECTION OF ESP

The instruments on the roof of the unit should be inspected first. This includes the transformer-rectifier (T-R) sets, rappers/vibrators, and insulators.

The inspector should examine insulators for moisture and tracking from arc-over. Cracks can be spotted with a bright light during an inspection. Corrosion of the insulator compartment (if it occurs) is another indication of moisture buildup. The inspector should check that the pressurization fan for the top housing or insulator compartment is operating properly, and that air filters for control sets and top housing are not plugged.

Rapper Noise

Rappers in fields of questionable performance should be checked audibly. Hopefully, this will be done by manually activating the units. However, this can also be accomplished in a passive, patient manner. A uniform, rhythmic tapping of metal to metal should be noted for rappers, and a loud buzzing sound from vibrators. A diagram of rapping timing and sequence is helpful. If reentrainment has been observed in steps 1 and 2, the timing, sequence and intensity of outlet field rappers should be monitored. Rapping intensity should be checked against design, as stack opacity may be reduced by reducing rapping intensity.

Air inleakage around access doors should be checked, especially if misalignment is suspected based on step 4, or excessive oxygen levels were found in step 3.

Air Infiltration

If the ductwork is accessible, the static pressure at various points should be inspected. Also, the physical condition of ducts should be observed to locate leaks. Some of the most common sites of infiltration are solids discharge valves, side access hatches, top access hatches, expansion joints, rapper shafts and the inlet duct. Air infiltration points are located by noting any obvious gaps and cracks and by listening for the sound of air movement.

The ducts entering the ESP should be checked for corrosion. If they are corroded, the interior of the ESP could also be corroded. The inspector should check for fugitive emissions at loose joints.

One way to quantify air infiltration is to make inlet and outlet oxygen measurements using portable instruments. However, this can be very difficult due to the size of the ducts. It is very difficult to traverse a duct with the equipment normally available to an inspector. A single point measurement down near the wall would be useful for finding very large air infiltration conditions.

An alternative approach would be to use the flue gas oxygen meters usually located before the air preheater as the ESP inlet value, and the CEM oxygen monitor in the stack as the ESP outlet value. This is far from ideal, because significant air infiltration can occur across the air preheater and in the precipitator outlet. However, this can provide a rough indicator of severe air infiltration problems in a precipitator system.

403.6 STEP 6: ASH HANDLING PROCEDURES

The inspector should check to see that the evacuation rate for the ash hoppers is quick enough to prevent buildup of ash over the tops of any of the hoppers. Inlet field hoppers normally collect from 60 to 80 percent of the total ash accumulated in an ESP, and must be evacuated much more often than the hoppers downstream.

If level alarms are used, the inspectors should determine that these are operating properly. The inspector should also check the temperature of the hoppers relative to each other. This can be done by simply touching each hopper throat with the back of the hand. If collected ash is allowed to cool, it becomes more prone to form bridges and plug up the inside of the hopper.

Problems the inspector should look for in the ash evacuation and removal system including ash buildup beneath ESP, holes or leaks, proper operation of discharge screw, disengagement of vacuum connections, malfunction of rotary air lock valves, and failure of sequencing controls.

403.7 STEP 7: EVALUATE PROCESS OPERATING CONDITIONS

The inspector should proceed to check a number of process parameters that can effect ESP performance. If possible, the following readings should be taken:

Gas flow rate;

Gas velocity;

Excess air;

Gas temperature;

Pressure drop across the ESP;

Moisture content;

Flue gas analysis (O_2, CO_2, etc.);

Soot blowing intervals.

Many of these instruments are located in the process control room and have continuous readouts. Variations in readings from process instruments from the normal design ranges should be investigated as to their possible effect on ESP performance, in conjunction with ESP control set readings, and visual observations made during the investigation.

403.8 STEP 8: INTERNAL INSPECTION – OPTIONAL

Optional for Regulatory Inspectors

If an ESP is down for scheduled maintenance or because of a malfunction, and an inspection is being done, the inspector should take time to perform some checks in addition to those already mentioned. These inspection techniques are similar to those the company should be doing during an annual inspection, but are not as detailed. These techniques are covered in section 605.2 of this manual. The regulatory inspector should focus on those fields already identified as trouble spots in previous steps of the inspection.

Items that the inspector should look at are:

1 Solids buildup on discharge electrodes, collection plates, and distribution plates;

2 Clearances near top and bottom of electrode assemblies;

3 Locations of removed wires;

4 Corroded areas, such as the underside of the roof plates, the outside wall, back of external stiffening members, and other areas not subject to continuous gas flow;

5 Insulator conditions (check for dust buildup and cracks).

The inspector should determine whether the source is making a good faith effort to minimize malfunctions by solving the principal causal factors.

Safety Measures

Before attempting to perform an internal inspection, personnel should ensure that all proper safety measures are observed. Section 605, which covers internal inspections, describes some necessary safety tests.

No internal inspection should be performed until it is certain that the ESP is deenergized and grounded, and necessary precautions are taken to ensure that the equipment cannot be energized during the inspection.

403.9 REVIEW OF OPERATING RECORDS

The inspector should review operating records from the process and ESP, both for completeness and for changes in operation that may have affected ESP performance. Table 502.1 lists a number of items for which records should ideally be kept. The records actually required from a regulatory standpoint will vary from plant to plant. The inspector should keep in mind that failure on the part of an operator to keep required records constitutes a violation of either air pollution regulations or permit conditions.

Legitimate Breakdowns

Diagnostic records, including discharge wire problems and air load tests, should be reviewed to confirm that reasonable attempts to reduce the frequency of malfunctions has been made. If the source has reported as "breakdowns" any ESP malfunctions that could have been avoided through regular maintenance practices, these do not meet the conditions to qualify as a legitimate breakdown per the district breakdown rule. Appropriate enforcement action should be taken.

404 COMPLIANCE ACTION

If the conditions observed during the inspection indicate that a citation is warranted, the inspector must clearly state to plant officials the grounds for such a citation. An onsite citation is justified only by clear-cut violations such as excessive opacity, corona power reduced below levels specified as a permit condition, or failure of the plant to report malfunctions or to maintain or provide required records for review. If ESP instrumentation values indicate to the inspector that the unit has problems severe enough to cause noncompliance, and noncompliance cannot be determined without a source test, the inspector should order a source test be performed.

Source Test

The inspector may issue an NOV for any permit condition that is violated. For example, if the temperature at which an ESP is operating is does not fall within the allowable range stated on the permit for inlet and outlet temperatures, an NOV may be issued.

The inspector should go over findings with the source operator before leaving the plant. He should explain all grounds for which he is issuing an NOV.

Districts process inspection reports according to their own policies and procedures. Typically, a copy of the inspection checklist is sent to the source with a letter confirming that the inspection was made, stating any deficiencies, and requesting that they be corrected within a reasonable time. Recommendations can be given for further improvements in operation and maintenance of the ESP, although many districts prefer that emphasis should be made toward indications of trouble and not the solution. The source should know what is expected, and the time frame it will have to accomplish the required action. Some type of implementation plan may be requested.

500 TROUBLESHOOTING

This chapter is written primarily for maintenance personnel at an industrial facility with an ESP.

Appendix C

Sample troubleshooting checklists are provided in appendix C.

501 PERFORMANCE MONITORING

Emissions Tests

Emissions tests, such as Reference Method 5, determine the compliance status of an operation. These tests are also useful in that measurements of parameters taken during such testingare at a known level of performance, and can serve as a benchmark or baseline condition for future comparisons with data collected during routine parameter monitoring and recordkeeping.

The establishment of these baseline conditions makes it possible for a number of parameters to be compared to determine their affect on performance. This comparison is especially useful for electrostatic precipitators (ESPs), because many parameters can affect performance to varying degrees. It is the magnitude of these changes that is important. Baseline conditions may also include air-load and gas-load tests in addition to the data obtained during emission testing.

Air Load Test

V-I Curves

For a new ESP, baselining includes an air-load test prior to operation while the plates and wires are in clean condition. An air-load test should be run on each field to generate a voltage-current (V-I) curve. When performing an air-load test, the collecting plate and discharge electrode rappers should be turned on, as should the insulator heaters and purge blowers. Then, using manual control, the voltage on each bus section should be raised in ten percent increments until the maximum current rating is attained. The current and voltage should be measured and recorded for each increment, and special note should be made of the voltage where the current flow begins (the voltage where the current is first non-zero; this is the minimum voltage at which the corona forms). Air-load curves, which are simply plots of the measured voltages and currents, should then be drawn.

For an air-load test, the values of the V-I relationship should be similar for fields of the same design. Items such as T-R capacity, square feet/T-R (sectionalization), and wire design (barbed vs. smooth) will influence the shape of the curves, as will any physical defect in construction. When the unit has been started up and operated, the air-load curves will be different because of the residual dust on the plates. Figure 501.1 shows graphs of typical air-load curves for all fields of an ESP.

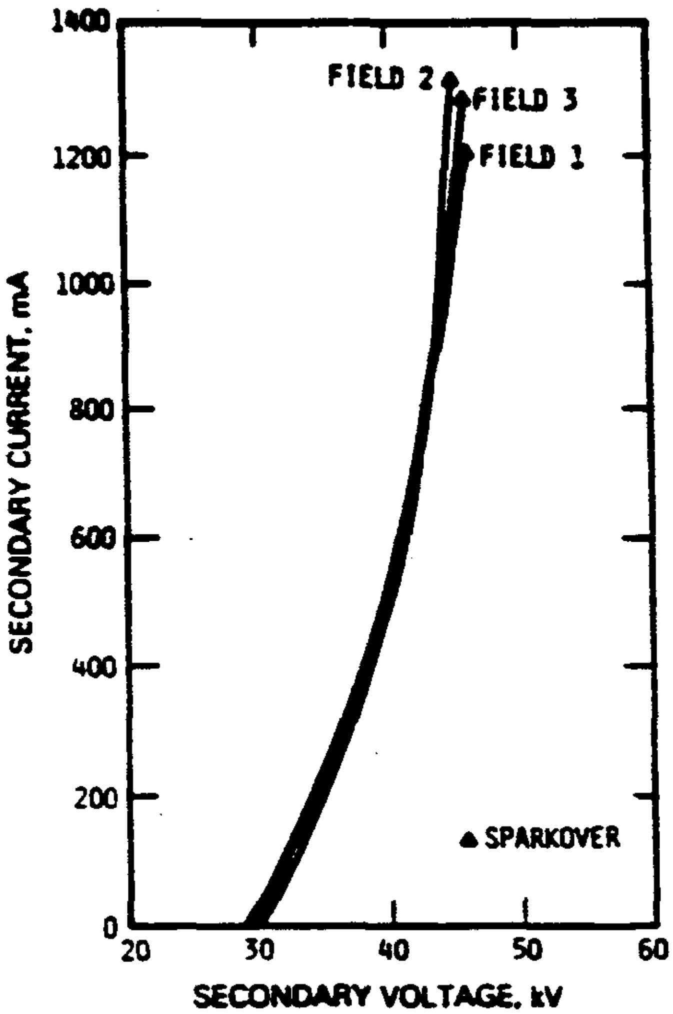


Figure 501.1 Typical Air Load Test V-I Curve [3]

Gas Load Tests

Gas load tests can be performed before or during a performance test. The gas-load test is performed under actual gas flow and particulate conditions to generate a V-I curve for each field. The corona start voltage should be noted, as should the maximum voltage achieved, especially if sparking occurs. The shape and length of the curves will vary somewhat because the process and ESP form a dynamic system. The absolute values of voltage and current are not as important as the trends observed with ESP performance. Figure 501.2 compares air-load and gas-load V-I curves.

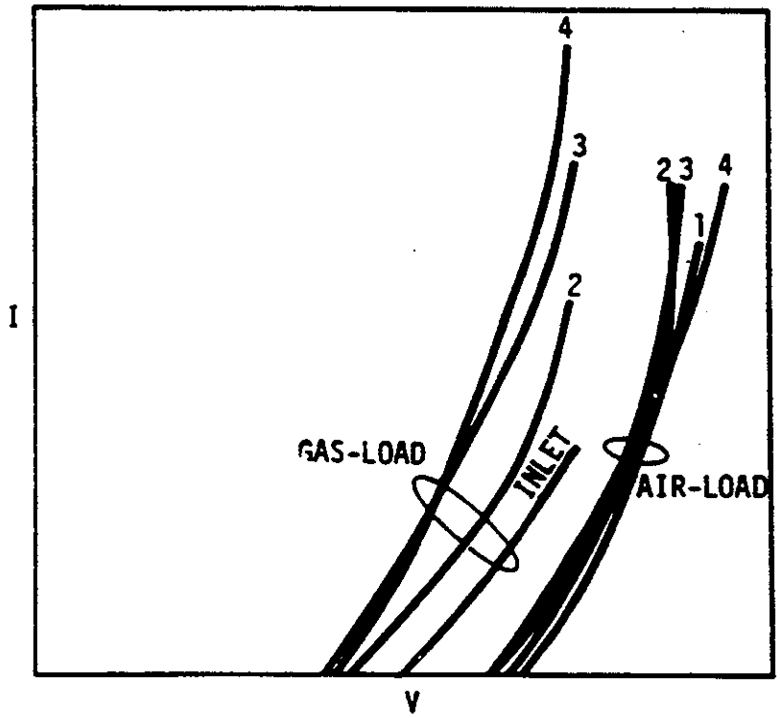


Figure 501.2 Comparison of Air Load and Gas Load Tests [3]

Parameter Monitoring

Parameter monitoring forms the basis of diagnostic recordkeeping and preventive maintenance. Several key parameters are usually monitored to track the ESP performance. Parameter monitoring includes both process and ESP data

because both are important to ESP performance. An analysis of these key parameters and a comparison with baseline values can define many performance problems, indicate the need for maintenance, and define operating trends within the ESP.
Typical parameters that can be monitored include opacity, corona power input, gas flow rate through the ESP, gas temperature and oxygen content, process operating rates, and conditioning systems (if used).

Many sources use opacity levels as a first indicator of performance changes. This is not advisable, because reliance upon opacity values as a first warning of problems can cause a source operator to miss other signs of problems that can affect long-term performance. For example, hopper pluggage may not increase opacity at reduced load, but it may misalign the affected fields and reduce their performance at full load or in other difficult operating situations.

Corona Power

Corona power input to the ESP is a useful parameter to monitor. Corona power can be thought of as the amount of work, per unit time, being done to remove particulate. This can be determined by multiplying the voltage and current values of either the primary or the secondary side of the transformer, although the secondary values are preferred. The ratio of the secondary power to the primary power will usually range from 0.5 to 0.9; the overall average for most ESPs is between 0.70 and 0.75. As a general rule, ESP performance improves as power input increases. This is not the case, however, when one encounters dust of either low or very high resistivity, or when spark rates are very high.

Power density is another parameter that is useful to monitor. Power density (watts per square foot of collection plate area) should increase from inlet to outlet fields as particulate matter is removed from the gas stream. Power density accounts for the differences in power inputs in a normally operating ESP by normalizing for field size.

If gas volume is known or estimated, the specific corona power (watts per 1000 acfm) can be calculated. This value tends to account for changes in performance due to different loads and power input because removal efficiency generally increases as thespecific corona power increases.

Spark Rate

Another parameter that is useful to monitor is the spark rate, or rate of sparking per minute in a given field. The spark rate for any field can be compared change in sparkrate may be a symptom of such problems as changes in the resistivity of the ash, misalignment of electrodes, air infiltration, or support insulator failure.

The spark rate can be read off a spark rate meter on a control cabinet. These gages, especially on older ESPs, are often inaccurate. If no gage is available, the spark rate can be estimated by counting the fluctuations of the primary voltage needle over a period of time. Typical spark rates vary widely from precipitator to precipitator, with values of anywhere from 30 to 150 per minute not being uncommon. With the newer automatic voltage controllers now in use, the low end of this range can be achieved, resulting in increased efficiency of particle collection.

500 TROUBLESHOOTING

502 RECORDKEEPING

Regulatory Requirements

Recordkeeping requirements vary from one plant to another, depending on the type of operation being controlled, the size of the operation, and its location. However, besides the regulatory recordkeeping obligations that a source may have, operators should consider keeping records of operating data and maintenance activities for the purposes of identifying potential problem areas and arriving at appropriate solutions.

Maintenance Activities

Operating Data

The magnitude of the recordkeeping activity will depend upon factors such as personnel availability, size of the ESP, and level of maintenance required. When setting up a recordkeeping program, one should give attention to both operating records and maintenance records as a means of preparing a complete operating history of the ESP. This operating history is useful in an evaluation of future performance, maintenance trends, and operating conditions that may increase the life of the unit and minimize emissions. This approach to recordkeeping makes the effort both worthwhile and cost-effective.

Other supplementary information that should be maintained include data from air-load tests conducted on the unit, all baseline assessments that include both process and ESP operating data, and data from emission tests.

Table 502.1 lists ESP design specifications for which records should be maintained. Figure 502.1 shows a typical plan layout for recording ESP operating data.

Table 502.1
ESP Design Specifications for which Records Should Be Maintained

A. Hardware Specifications
Manufacturer Model Year installed Collection plate area (total) Number of chambers Number of fields Plate spacing Plate height Plate width Number of lanes/section Cross-sectional area/section Linear feet of discharge wire Rapper type, plate Rapper type, wires Rapper acceleration, plate Rapper acceleration, wires
B. Electrical Specifications
Corona power total Corona power per unit volume of gas Number of T-R sets Rating(s) of T-R set Average primary voltage Average primary current Average secondary voltage Average secondary current Average current density per plate area * Average current density per electrode length *
C. Application Specifications
Gas flowrate, total Gas temperature, inlet Gas temperature, outlet Gas composition (N2, O2, SOx, etc.) Gas velocity, superficial * Gas velocity, distribution, standard deviation Specific collection area * Collection efficiency Particulate concentration, inlet Particulate concentration, outlet Particle size distribution, inlet Particle size distribution, outlet Precipitation rate parameter * (particle migration velocity) Resistivity value (or range)
* Parameters that can be calculated from other given values.

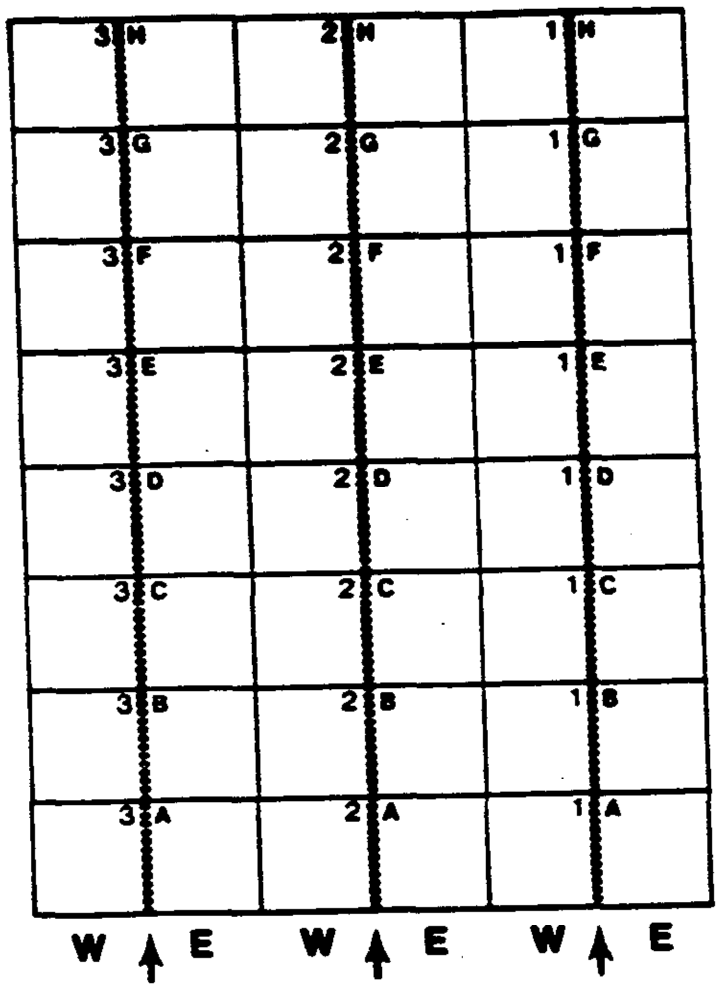


Figure 502.1 Typical Plan Layout for Recording ESP Operating Data [3]

503 PROBLEM DIAGNOSIS

Many ESP operating problems are reflected in the electrical operating characteristics. In a typical, well-designed, operated, and maintained ESP (without resistivity problems), a pattern of increasing current and decreasing voltage from the inlet fields to the outlet fields can be expected. It is important to be familiar with the operating characteristics of the ESP and to know what is typical. Recordkeeping, as discussed in section 502, helps the operator to be more knowledgeable.

Recordkeeping

One of the difficulties in assessing ESP performance is that many different problems produce the same electrical characteristics on the panel meters. For this reason, plant personnel obtain additional data to reduce the number of possible causes to one or two. In addition, synergism often causes the original problem or failure to lead to additional problems that can cascade into even more problems. When this occurs, it is often difficult to identify the original cause of a problem. Nevertheless, it is usually more important to identify and correct all causal factors than to simply treat the symptom.

The key to diagnostic troubleshooting is to know the precipitator's characteristics; to understand what the meter readings mean; and to use all the process, opacity, and electrical data to assist in the evaluation. An internal inspection may even be necessary to confirm of eliminate possible sources of problems.

Most major performance problems can be categorized into the following areas: resistivity; hopper pluggage; air inleakage; dust buildup; wire breakage; rapper failure; inadequate power supplies and/or plate area; changes in particle size; and misalignment of internal components. Some of these problems are related to design limitations, operational changes, maintenance procedures, or a combination thereof. The identification of these problems and their affect on ESP performance is discussed here. Possible corection measures are described in section 504.

503.1 PROBLEMS RELATED TO RESISTIVITY

The resistivity of the dust on the collection plate affects the acceptable current density through the dust layer, the ability to remove the dust from the plates, and indirectly, the corona charging process. Because the optimum resistivity range for ESP operation is relatively narrow, however, both high and low resistivity cause problems.

503.1.1 High Resistivity

The most common resistivity problem is that caused by high dust resistivity. The particles acquire charge from the corona charging process and migrate to the collection plate. Once there, however, high resistivity particles neither give up very much of their acquired charge, nor easily pass the corona current to the grounded collection plates. As the dust layer buildup continues, the resistance to current flow increases. The controller responds by "opening up" the silicon controlled rectifiers (SCRs) more to increase the voltage level. Although this would occur with almost all particulates, the detrimental effect on ESP performance is more pronounced when particle resistivity is high.

Ohm's Law

Electric Field Breakdown

The voltage drop in the dust layer may be substantial. The dust layer voltage drop (which depends on the resistivity and thickness of the dust layer) can be approximated by Ohm's Law. As the current increases, the voltage drop also increases. The average electric field in the particulate layer can be increased to the point that the gas in the interstitial space breaks down electrically. With particulate of increased resistivity, the current at which this breakdown occurs will decrease. It is this electrical breakdown of the gas in the dust layer that diminishes the ESP performance. Figure 503.1 shows voltage-current (V-I) characteristics of an inlet section of an ESP collecting high resistivity ash.

When this breakdown occurs, one of two possible situations will ensue. If the electrical resistivity of the particulate layer is moderate, then the applied voltage may be sufficiently high so that a spark will propagate across the interelectrode space. The rate of sparking for a given precipitator geometry will determine the operating electrical conditions in such a circumstance.

Optimum Resistivity

The optimum resistivity range is generally between 10^8 and 10^{10} ohm-cm. Performance of the ESP generally does not diminish until approximately 2×10^{11} ohm-cm. High-temperature gas streams at the 600 °F to 700 °F level could possibly exhibit resistivity problems at 10^{10} ohm-cm because of low gas density. Conversely, high altitudes will also tend to reduce the resistivity level at which problems may occur.

At this level the breakdown of the dust layer may be limited, but it can be aggravated by unequal buildup on the plates, and the response of the controller to increase the operating voltage may exceed the voltage required for spark propagation. Thus, when the dust layer does break down, the resistance to

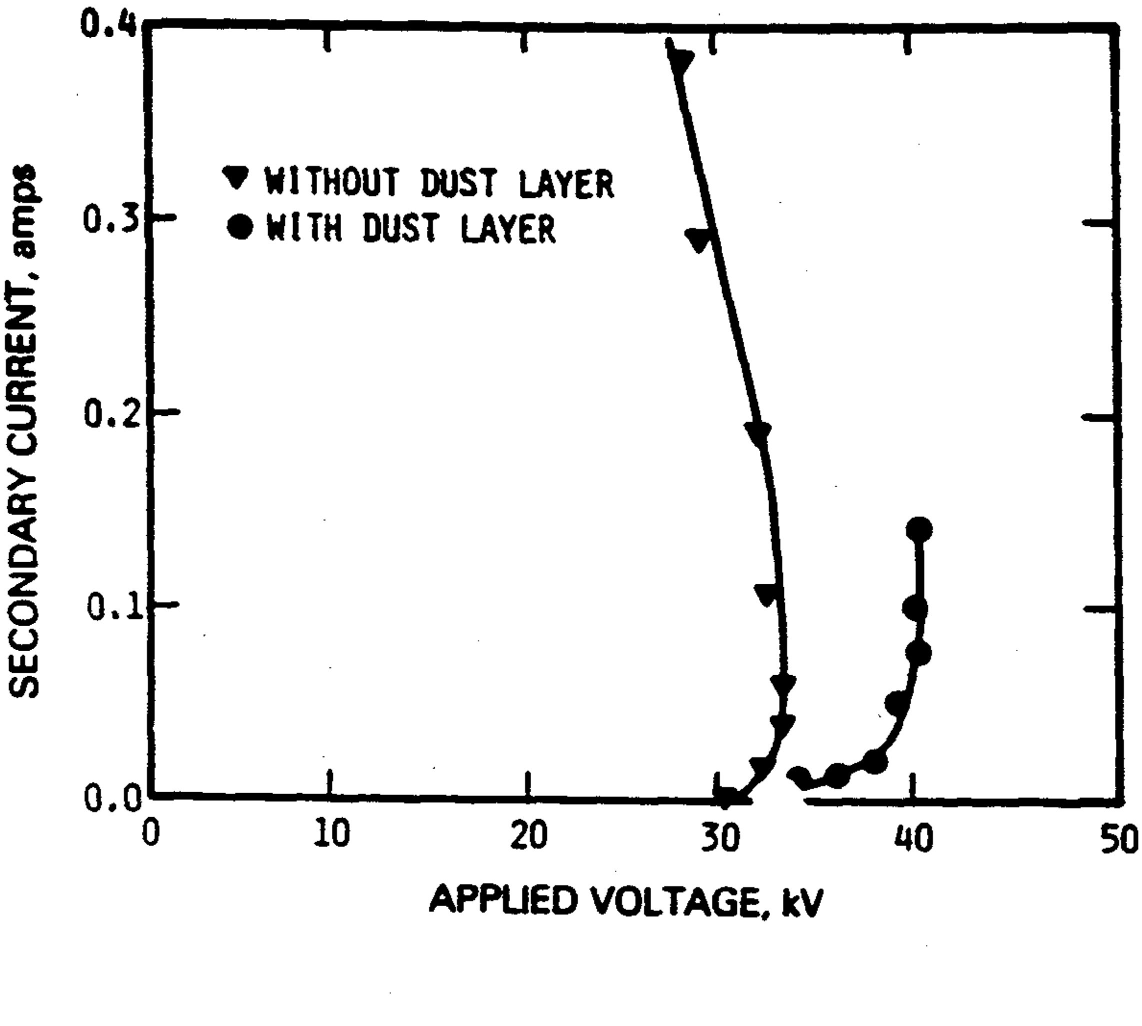


Figure 503.1 V-I Characteristics for High Resistivity Ash [3]

current flow is suddenly reduced and a spark is formed. An identifying characteristic of high resistivity is the tendency toward high spark rates at low current levels throughout the ESP, which often makes it difficult for the T-R controller to respond and function adequately.

If the resistivity of the particulate layer is high (> 10^{13} ohm-cm), the applied voltage may not be high enough to cause a spark to propagate across the interelectrode space. In this case, the particulate layer will be continuously broken down electrically and will discharge positive ions into the interelectrode space. This condition is called back corona.

Back Corona

The effect of these positive ions is to reduce the the amount of negative charge on a particle due to bipolar charging and reduce the electric field associated with the ionic space charge. Both the magnitude of particle charge and rate of particle charging are affected by back corona. Useful precipitator current is therefore limited to values which occur prior to electrical breakdown whether the breakdown occurs as sparkover or back corona.

Rapping Problems

High resistivity also tends to promote rapping problems, as the electrical properties of the dust tend to make it very tenacious. High voltage drop through the dust layer and the retention of electrical charge by the particles make the dust difficult to remove because of its strong attraction to the plate. In addition to the reduced migration and collection rate associated with high resistivity dust, greater rapping forces usually required to dislodge the dust may also aggravate or cause a rapping reentrainment problem.

It is important to remember that the difficulty in removing high resistivity dust is related to the electrical characteristics and not to the sticky or cohesive nature of the dust. Also, the ESP must be able to withstand the necessary rapping forces applied without mechanical damage to the insulators or collection plate systems.

503.1.2 Low Resistivity

Low dust resistivity can be just as detrimental to the performance of an ESP as high resistivity. Low resistivity refers to the inability of particles to retain a charge once they have been collected on the plate.

As in the normal resistivity and high resistivity cases, the ability of the particulate matter to obtain a charge is not affected by its resistivity. Particle charging occurs by the previously discussed charging mechanisms, which are dependant on particle size.

Low Binding Forces

Once the particles are at the collection plate, however, they release much of their acquired charge, and are capable of passing the corona current quite easily. Thus, attractive and repulsive electrical forces that are normally at work at higher electrical resistivities are lacking, and the binding forces to the plates are considerably lessened. Particle reentrainment is a substantial problem at low resistivity, and ESP performance appears to be very sensitive to contributors of reentrainment, such as poor rapping or poor gas distribution.

Reentrainment

The voltage drop across the dust layer on the plate is usually small. The lower resistance to curent flow than in optimum and high resistivity ranges means that lower operating voltages are required to obtain substantial current flow. Thus, operating voltages and currents are typically close to clean plate operations, even when there is some dust accumulation on the plate. A typical low resistivity condition is reflected by low operating voltages and high current flow. These electrical conditions may look very similar to those of high resistivity with well-developed back corona. The result is usually the same -- reduced ESP performance.

Despite the high currents encountered under low resistivity conditions, the corresponding low voltages yield lower migration velocities to the plate. Thus, particles of a given size take longer to reach the plate than would be expected. When combined with substantial reentrainment, the result is poor ESP performance. In this case, the large flow of power to the ESP represents a waste of power.

Enrichment

The low resistivity problem typically results from the chemical characteristics of the particulate and not from temperature. The particulate may be enriched with compounds that are inherently low in resistivity, either because of poor operation of the process or the inherent nature of the process.

Examples of such enrichment include excessive carbon levels in fly ash (due to poor combustion), the presence of naturally occuring alkalies in wood ash, iron oxide in steel-making operations, or the presence of other low-resistivity materials in the dust.

Over-conditioning may also occur in some process operations, such as the burning of high-sulfur coals or the presence of high SO_3 levels in the gas stream, both of which lower the inherent resistivity of the dust. In some instances, large ESPs with specific collection areas (SCA) values greater than 750 ft^2/1000 acfm have performed poorly because of the failure to comprehend fully the difficulty involved in collecting low resistivity dust. Although some corrective actions are available, they are sometimes more difficult to implement than those for high resistivity. Fortunately, low resistivity problems do not occur as frequently as high resistivity problems.

503.2 EXCESSIVE DUST ACCUMULATION ON ELECTRODES

Where no ash resistivity problem exists, the cause for excessive dust accumulation in an ESP is often external. When buildup of material on the discharge electrodes and collecting electrodes or plates is difficult to distinguish in an operating ESP, differences in the V-I curves can often point out the nature of the problem.

Buildup on the discharge electrodes (whether straight-wired, barbed-wired or rigid) often means an increase in voltage to maintain a given operating current. The effect of dust buildup on the discharge electrodes is usually equivalent to changing the effective wire diameter. Since the corona starting voltage is a strong function of wire diameter, the corona starting voltage tends to increase and the whole V-I curve tends to shift to the right, as shown in figure 503.2.

Sparking tends to occur at the same voltage unless resistivity is high. This effect in corona starting voltage is usually more pronounced when straight wires are uniformly coated with a heavy dust, and less pronounced on barbed wires and rigid electrodes or when the dust layer is not uniform. Barbed wires and rigid electrodes tend to keep the "points" relatively clean, and tend to maintain a small effective wire diameter, and therefore, a low corona starting voltage.

Under normal operating conditions, most of the dust is collected at the plate, and relatively little would collect on the wires. The dust that collects on the wires is usually dust that enters the corona discharge area with the proper trajectory to attach to the wire. The material collected on the plate is usually allowed to build up for some specified length of time to take advantage of cohesive forces between particles. It is then dislodged by activation of a rapper.

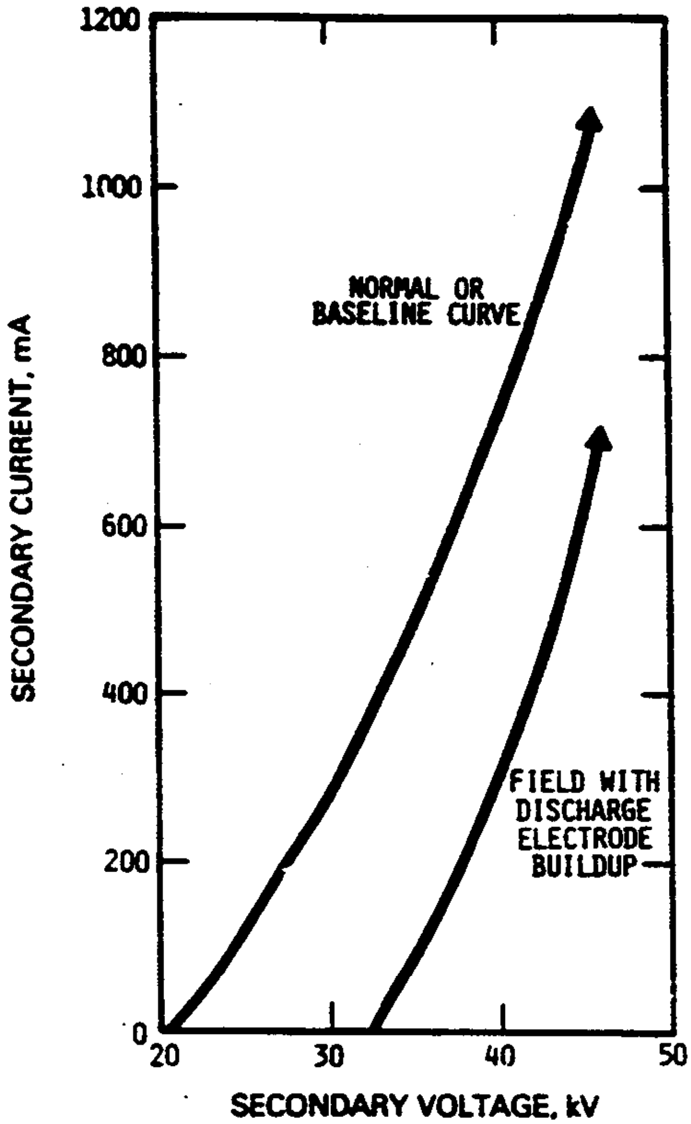


Figure 503.2 V-I Curve for Field With Excessive Wire Buildup [3]

500 TROUBLESHOOTING

The dust buildup usually changes the electrical characteristics of the field and causes a shift in voltage and current over the period of the buildup. This variation in the amount of dust on the plates is one reason why readings of panel meters may vary from observation to observation.

In general, the dust buildup on a clean plate, as on electrode wires, increases the voltage to maintain a given current level. This effect is normally most apparent on a middle or outlet field of an ESP, where the time between rapping periods is sufficiently long to allow a substantial dust layer to build up. Electrical readings taken just before and just after a rapping cycle should indicate decreased operating voltage and a decreased or constant current level. The dust layer presents a resistance to current flow, and the operating voltage must be increased to overcome this resistance. The dust layer on the plates has relatively little effect on corona starting voltage.

Gas Velocity Increases

If the dust layer buildup were relatively even, it might be expected to continue right up to the T-R capacity. In practice, however, dust buildup usually reaches a thickness of between 3/4 and 1 inch under normal resistivity conditions before performance is markedly reduced. As the thickness (and the operating voltage) increases, the clearance between the discharge electrode and the surface of the dust layer on the collection plates decreases. This encourages the occurence of sparking within the precipitator. The precipitator controls then respond by decreasing operating voltage and current, which lowers the charging and migration rates. This in turn causes the volume occupied by the ash within the precipitator to increase, and the gas velocity between the plates must also increase to maintain a given flowrate. If the increased velocity exceeds 6 to 8 ft/s, reentrainment is likely to occur and reduce performance further. In some cases the dust layer will become self-limiting because of the gas velocity through the ESP.

Rapping Failures

The usual cause for buidup on the collection plates or discharge wires is failure of the rapping system or an inadequate rapping system. The rapping system must provide sufficient force to dislodge the dust without damaging the ESP or causing excessive reentainment. The failure of one or two isolated rappers does not usually degrade ESP performance significantly. The failure of an entire rapper control system or all the rappers in one field, however, can cause a noticeable decrease in ESP performance, particularly with high resistivity dust. Therefore, rapper operation should be checked at least once per shift. A convenient time to make this check is during routine T-R set readings.

In rare cases, rapping is not necessary. These usually involve low resistivity dust that requires very little energy to remove, or actually dislodges by virtue of its own weight. Also, no rappers are associated with the collection surface in wet ESPs, but they may be used for the discharge electrodes.

Dewpoint

Excessive dust buildup may also result from sticky dusts or dewpoint conditions. In some cases, the dusts may be removed by increasing the temperature, but in many cases the ESP must be entered and washed out. If sticky particulates are expected (such as tars and asphalts), a wet-wall ESP is usually appropriate because problems can occur when large quantities of sticky particles enter a dry ESP. Among the cases where this may be a problem are ESPs applied to wood-fired boilers, municipal incinerators, and some coal-fired boilers. The problem usually occurs when improper combustion yields a partially combusted, sticky, hydrocarbon material. This can also present a fire hazard and potential low resistivity problems.

In the pulp and paper industry, sticky particulate has been noted during periods of high excess air levels in recovery boilers burning black liquor. Concentrations of SO_3 tend to increase. These result in a raised acid dewpoint, since the SO_2 is absorbed on the particulate at the relatively low temperatures in the economizer and ESP. This sticky salt cake can be difficult to remove from both the economizers and the ESP. This situation can be further aggravated by the combustion of residual fuel oil containing vanadium. Some of the vanadium complexes formed may be insoluble in water and would therefore be difficult to wash off the plates.

503.3 WIRE BREAKAGE

Some ESPs operate for 10 to 15 years without experiencing a single wire breakage, whereas others encounter serious problems causing one or more sections to be out of service nearly every day of operation. The most common ESP in service today is the weighted-wire type. Most of the newer ESPs in the field are of the rigid-frame and rigid-electrode design. These use shorter wires or no wires at all, and are far less prone to wire breakage than the weighted-wire type.

Location

Wires usually fail in one of three areas: at the top of the wire; at the bottom of the wire; and wherever misalignment or slack wires reduce the clearance between the wire and plate. Wire failure may be due to electrical erosion, mechanical erosion, corrosion, or some combination of these. When wire failures occur, they usually short out the field where they are located,and may occasionally short out an adjacent field.

Thus, the failure of one wire can cause the loss of collection efficiencies in an entire field or bus section. In some smaller ESP applications, this can represent one third to one half of the charging/collecting area and thus substantially limit ESP performance. One of the advantages of higher sectionalization is that wire failure affects smaller areas so ESP performance does not suffer as much. Some ESPs are designed to meet emission standards with some percentage of the ESP deenergized, whereas others may not have any margin to cover down-time. Inlet fields are usually more important to ESP operations than outlet fields.

Misalignment

Misalignment of the discharge electrodes relative to the plates increases the potential for broken wires, decreases the operating voltage and current because of sparking, and decreases the performance potential of that field in the ESP. Sparking usually occurs at points where there is close clearance within a field (due to a warped plate, misaligned guidance frames, or bowed wires). The maximum operating voltage is usually limited by these close tolerance areas because the spark-over voltage is lowered by the reduction in the distance between the wire and the plate.

Sparking

Under normal circumstances random sparking does little damage to the ESP. During sparking, most of the power applied to energize the field is directed to the location of the spark, and the voltage field around the remaining wires collapses. The considerable quantity of energy available during the spark is usually sufficient to vaporize a small quantity of metal. When sparking continues to occur at the same location, the wire usually "necks down" because of electrical erosion until it is unable to withstand the tension and it breaks.

Although the breakage of wires at the top and bottom where the wire passes through the field can be aggravated by misalignment, the distortion of the electrical field at the edges of the plate tends to be the cause of breakage. This distortion of the field, which occurs where the wire passes the end of the plate, tends to promote sparking and gradual electrical erosion of the wires. The methods available to minimize this particular failure are discussed in section 504.4.

Both design considerations and the failure to maintain alignment generally contribute to mechanical erosion (or wear) of the wire. In some designs, the lower guide frame guides the wires or their weight hooks (not the weights themselves) into alignment with the plates. When alignment is good, the guide frame or grid allows the wires or weight hooks to float freely within their respective openings. When the position of the wire guide frame shifts, however, the wire or weight hook rubs the wire frame within the particulate-laden gas stream. Failures of this type usually result from a combination of mechanical and electrical erosion. Corrosion may also contribute to this failure. Microsparking action between the guide frame and the wire or weight hook apparently causes the electrical erosion. The same type of failure also can occur in some rigid frame designs where the wires ride in the frame.

Another failure that sometimes occurs involves crossed wires. This happens when those who replace wires do not check to see that the replacement wire does not cross another wire. Eventually, the resulting wearing action breaks one or both wires. If one of the wires does survive, it is usually worn down enough to promote greater sparking at the point of contact until it finally does break. When wires are replaced, care should be taken to see that wires are not crossed. Any wires that are found to be exceptionally long and slack should be replaced; they should not be crossed with another wire to achieve the desired length.

Corrosion

Corrosion of the wires can also lead to wire failures. Corrosion, an electrochemical reaction, can occur for several reasons, the most common being operating temperatures below acid dewpoint. When the rate of corrosion is slow and generally spread throughout the ESP, it may not lead to a single wire failure for 5 to 10 years. When the rate of corrosion is high because of long periods below the acid dewpoint, failures are frequent. In these cases the corrosion problem is more likely to be a localized one; e.g., in places where cooling of the gas stream occurs, such as in leakage points and the walls of the ESP.

Corrosion-related wire failures can also be aggravated by startup/shutdown procedures that allow the gas streams to pass through the dewpoint many times. Many facilities have experienced wire breakage problems during the initial process shakedown period when the process operation may not be continuous. Once steady operations has been achieved, wire breakage problems tend to diminish at most plants. Some applications that routinely start up and shut down (small "peaking" utilities, for example) have had relatively few problems with wire breakage. Good operating practices and startup/shutdown procedures help to minimize this problem.

Another cause of wire failure is wire crimping. These crimps usually occur at the top and bottom of the wires where they attach to the upper wire frame or bottle weight; however, a crimp may occur at any point along the wire. A crimp can mechanically weaken and thin a wire. It can also cause a distortion of the electric field along the wire, which promotes sparking, and it can subject the wire to a stress corrosion failure (materials under stress tend to corrode more rapidly than those not under stress). Because a crimp creates a residual stress point, all three mechanisims may be at work in this situation.

Wire failure should not be a severe maintenance problem or operating limitation in a well-designed ESP. Excessive wire failures are usually a symptom of a more fundamental problem. Plant personnel should maintain records of wire failure locations. Although ESP performance will generally not suffer with up to approximately 10 percent of the wires removed, these records should be maintained to help avoid a condition in which entire gas lanes may be deenergized. Improved sectionalization helps to minimize the effect of a broken wire on ESP performance, but performance usually begins to suffer when large percentages of the ESP are deenergized.

503.4 HOPPER PLUGGAGE

Perhaps no other problem (except fire or explosion) has the potential for degrading ESP performance as much as hopper pluggage. Hopper pluggage can permanently damage an ESP and severely affect both short-term and long-term performance. Hopper pluggage is difficult to diagnose because its effect is not immediately apparent on the T-R panel meters. Depending on its location, a hopper can usually be filled in 4 to 24 hours. In many cases, the effect of pluggage does not show up in the electrical readings until the hopper is nearly full.

The electrical reaction to most plugged hoppers is the same as that for internal misalignment, a loose wire in the ESP, or excessive dust buildup on the plates. Typical symptoms include heavy or "Bursty" sparking in the field(s) over the plugged hopper and reduced voltage and current in response to the reduced clearance and higher spark rate. In weighted-wire designs, the dust may raise the weights and cause slack wires and increased arcing within the ESP. In many cases, this will trip the T-R off-line because of overcurrent or undervoltage protection circuits. In some situations, the sparking continues even as the dust builds between the plate and the wire; whereas in others, the voltage continues to decrease as the current increases and little or no sparking occurs. This drain of power away from corona generation renders the field virtually useless. The flow of current also can cause the formation of a dust clinker resulting from the heating of the dust between the wire and plate.

Clinker

The buildup of dust under and into the collection area can cause the plate or discharge electrode guide frames to shift. The buildup can also place these frames under enough pressure to distort them or to cause permanent warping of the collection plate(s). If this happens, performance of the affected field remains diminished by misalignment, even after the hopper is cleared.

Warping

The causes of hopper pluggage include such things as obstructions due to fallen wires and/or bottle weights, inadequately sized solids-removal equipment, use of hoppers for dust storage, inadequate insulation and hopper heating, and inleakage through access doors. Most dusts flow best when they are hot, and cooling the dusts also can promote a hopper pluggage problem.

Hopper pluggage can begin and perpetuate a cycle of failure in the ESP. For example, in one ESP, a severely plugged hopper misaligned both the plates and the wire guide grid. When the hopper was cleared, the performance of this field had decreased and the wires and weight hooks were rubbing the lower guide and causing erosion of the metal. When the metal eventually wore through, hopper pluggage increased as weights (and sometimes wires) fell into the hopper, plugging the throat, and allowed the hopper to fill again and cause more misalignment. The rate of failure continued to increase until it was almost an everyday occurence. This problem, which has occured more than once in different applications, points out how one relatively simple problem can lead to more complicated and costly problems.

In most pyramid-shaped hoppers, the rate of buildup lessens as the hopper is filled (because of the geometry of the inverted pyramid). Hopper level indicators or alarms should provide some margin of safety so that plant personnel can respond before the hopper is filled. The rate of deposition in the hopper also will diminish when the top of the dust layer interferes with the electrical characteristics of the field, which reduces the collection efficiency. Lastly, reentrainment of the dust from the hopper can also limit how far up into the field the dust can go. Although buildups as deep as 4 ft. have been observed, they usually are limited to 12 to 18 in. up from the bottom of the plates.

Alarms

503.5 MISALIGNMENT

As mentioned several times in the previous sections, misalignment is both a contributor to and a result of component failures. In general, most ESPs are not affected by a misalignment of less than about 3/16 in. Indeed, some tolerance must be provided for expansion and contraction of the components. Beyond this limit, however, misalignment can become a limiting factor in ESP performance and is usually visually evident during an internal inspection of the ESP.

Whether caused by warped plates, misaligned or skewed discharge guide frames, insulator failure, or failure to maintain ESP "box-squareness," misalignment reduces the operating voltage and current required for sparking. The V-I curve would indicate a somewhat lower voltage to achieve a low current level with the sparking voltage and current greatly reduced (see figure 503.3). Since the maximum operating voltage/current levels are dependent on the path of least resistance in a field, any point of close tolerance will control these levels.

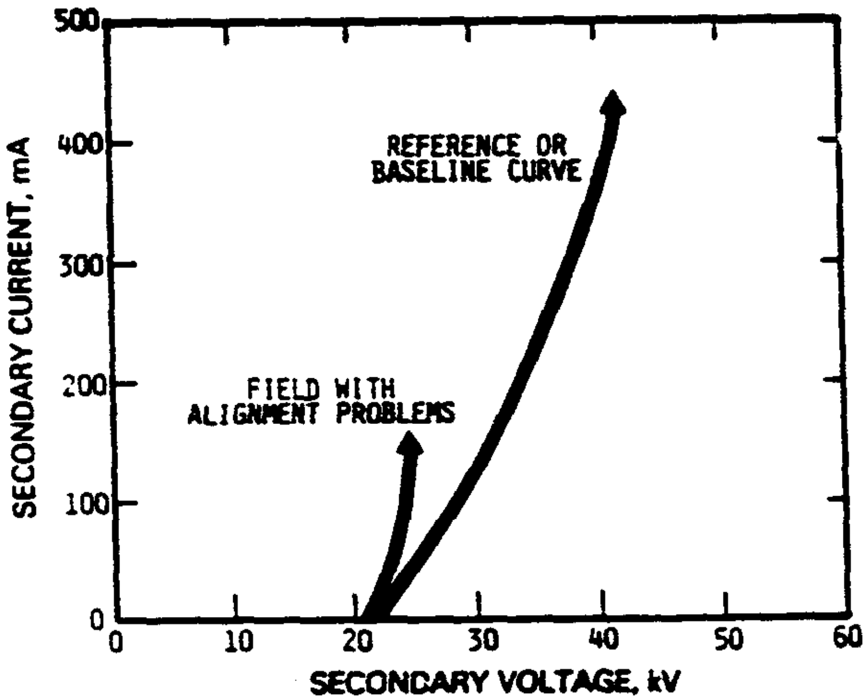


Figure 503.3 V-I Curve for Field With Alignment Problems [7]

503.6 UNUSUALLY FINE PARTICLE SIZE

Unusually fine particles present a problem if (1) the ESP was not designed to handle them, or (2) a process change or modification shifts the particle size distribution into the range where ESP performance is poorest. A shift in particle size distribution tends to alter electrical characteristics and increase the number of particles emitted in the light-scattering size ranges (opacity).

As we discussed in Section 301, there are two basic charging mechanisms: field charging and diffusion charging. Although field charging tends to dominate in the ESP and acts on particles greater than 1 micrometer in diameter, it cannot charge and capture smaller particles. Diffusion charging, on the other hand, works well for particles smaller than 0.1 micrometer in diameter. For particles between 0.1 and 1.0 micrometer in diameter, and particularly in the range of 0.2 to 0.5 micrometer, performance of the ESP diminishes considerably. Because neither charging mechanism is very effective, particles in this range are more difficult to charge; and once charged, they are easily bumped around by the gas stream, which makes them difficult to collect. The collection efficiency of an ESP can drop from as high as 99.9+ percent on particles sized above 1.0 micrometer and below 0.1 micrometer, to only 85 to 90 percent on particles in the 0.2 to 0.5 micrometer diameter range, depending upon the type of source being controlled. If a significant quantity of particles fall into this range, the ESP design must be altered to accommodate the fine particles. Figure 303.5 shows a typical curve of the relationship between efficiency and particle size.

Corona Quenching

Two significant electrical effects of fine particles are space charge and corona quenching, which occur when heavy loadings of fine particles enter the ESP. At moderate resistivities, the space-charge effects normally occur in the inlet or perhaps the second field of ESPs. The T-R controller responds to heavy loadings by increasing the operating voltage to maintain current flow and corona generation. The increase in voltage usually causes increased spark rates, which may in turn reduce the voltage and current to maintain a reasonable spark rate. As the particles move through the ESP and are collected by the plates, the gas stream becomes cleaner. As a result, the voltage level will usually decrease in subsequent fields, and current levels will increase markedly. As quantities of fine particles are increased, the space charging effect may progress further into the ESP.

Corona quenching can also result when the quantity of particles is so great that relatively few electrons even reach the plate in the inlet field. This condition is characterized by very high voltages and extremely low current. An example of this type of situation would be a raw mill where an ESP is used to control particulates from a preheater or precalciner kiln and all of the material leaving the mill's preheater/precalciner enter the ESP. Grain loadings up to 165 to 200 gr/acf could be encountered, and the ESP must be able to handle this quantity of material.

503.7 INLEAKAGE

Inleakage is often overlooked as an operating problem. In some instances, it can be beneficial to ESP performance, but in most cases its effect is detrimental. Some of the causes of inleakage, which may occur at the process itself or at the ESP, are leaking access doors, leaking ductwork, and even open sample ports.

Temperature Changes

Reentrainment

Hopper Pluggage

Inleakage usually cools the gas stream, and it can also introduce additional moisture. The result is often localized corrosion of the ESP shell, plates, and wires. The temperature differential also could cause electrical disturbances (sparking) in the field. Finally, the introduction of the ambient air can effect the gas distribution near the point of entry. The primary entrance parts are through the access doors. Inleakage through hopper doors may reentrain and excessively cool the dust in the hopper, which can cause both reentrainment in the gas stream and hopper pluggage. Inleakage through the access doors is normally accompanied by an audible in-rush of air.

Velocity Changes

Inleakage is also accompanied by an increase in gas flowrate. This can cause an increase in emissions due to higher velocities through the ESP. Velocities in the ESP may double in extreme cases, causing captured material to be blown off the plate. In such cases the source will probably not meet emission standards.

503.8 SUMMARY

Determine Causes

Familiarity with ESP operating characteristics, failure modes, and design factors aid in the diagnosis of ESP performance. As pointed out in the discussion, many problems produce similar symptoms in T-R set meter readings. Gathering process data and generating V-I curves add data that are useful for diagnostic troubleshooting, but usually a process of elimination is necessary to narrow the possible causes of problems to one or two areas. To the extent possible, maintenance personnel should try to determine the cause of the problem, not merely try to treat a symptom. This approach often identifies the corrective actions necessary to avoid more problems in the future, whereas the "band-aid" approach is more likely to cause more problems in the future. Recordkeeping is also very important in the evaluation of both short and long term ESP performance.

504 CORRECTIVE ACTIONS

When the data collected indicate that a problem exists, plant personnel must decide what action should be taken. Sometimes the initial cause of the problem is hard to define, even though the results and symptoms clearly indicate its existance. In other cases, the problem is easily identifiable, but more than one choice for corrective action is available. The options available to plant personnel for the various problem areas discussed in section 503 are presented in the following sections.

504.1 CORRECTION OF RESISTIVITY-RELATED PROBLEMS

When examining the alternatives for correcting resistivity problems, plant personnel should ask three questions:

1 How often does this problem occur?

2 Can the process or materials be changed to eliminate the problem?

3 Is the operation of the ESP optimal, or are there design limitations that cannot be overcome?

The answers to these questions may eliminate certain options and enhance the feasibility of others.

For long-term resistivity problems, an option with high initial costs may be most cost-effective when lost production and increased maintenance are considered. When resistivity problems are intermittent, however, changes in process operating parameters may offer a better solution.

Adjust Temperature

One of the simplest changes in process operation is to raise or lower the gas temperature to increase either the surface conduction or bulk conduction mechanisms. This is particularly useful when the resistivity-versus-temperature curves are steep and have a relatively sharp peak. In some situations, a change of only 20 °F to 30 °F may be all that is required to modify the resistivity and improve ESP performance. The disadvantages of changing the gas temperature include an increased potential for corrosion from acid dewpoint conditions if the temperature is lowered, and an increase in energy loss due to a higher gas temperature. The peak resistivity often occurs at or near the optimum temperature for the process. In addition, some multi-chambered ESPs may show symptoms of high resistivity only in some chambers because of the difference in operating temperatures between chambers.

Moisture Addition

The addition of moisture to the gas stream may be an acceptable method for conditioning the gas stream and improving performance. The moisture changes the dewpoint levels, enhances the condition of the particulate matter, and, by increasing the dielectric strength of the gas, the electric field is less likely to break down and spark. The evaporation of water droplets used to condition the gas stream will also cool the gas stream and further condition it. The water droplets must be properly atomized to provide good evaporation without excessive water use or carryover into the ESP. This often requires the use of air-atomized sonic nozzles. In some ESP operations, the use of moisture conditioning is essential to the capture of particulate. Two examples are salt cake recovery in kraft mills and cement dust control in cement plants. Whether the presence of moisture is inherent to the process (as in the case of kraft recovery process or wet process cement kilns) or due to external addition (as in dry processes, some preheat situations, or precalciner cement kilns), the lack of moisture would make it difficult to capture the particulate matter because of its high resistivity.

Process Changes

Another alternative solution for ash resistivity problems involves a change in process feed or operation to modify the chemical characteristics of the dust to be captured. Care must be taken to avoid boiler problems such as slagging or fouling of boiler tubes due to the incompatibility of ash and furnace conditions. Another alternative available to a boiler operator is to lower the combustion efficiency and allow more unburned carbon into the ESP. Although this may reduce boiler efficiency, the presence of small amounts of carbon can act as a conditioning agent and reduce the resistivity of the fly ash. The trade-off in some situations is worthwhile because the slight loss in efficiency is offset by the ability to maintain load rather than to reduce the load to maintain the opacity limitation. Care must be taken not to overuse this solution, however. In some processes, such as cement kilns or municipal incinerators, it may not be possible to change or control the feed characteristics to maintain acceptable resistivity characteristics.

Low resistivity problems are often more difficult to correct. Low superficial gas velocities and optimization of rapper operation and rapping pattern can help to minimize reentrainment problems commonly encountered with low resistivity dusts; however, generating the force necessary to keep the collected dust on the plates is difficult. If gas temperature is a problem, one alternative is to increase the temperature towards the peak resistivity. The problem is usually related to the process characteristics rather than gas temperature, however. Previously cited examples include high-sulfur fuel, excessive carbon levels, and the presence of natural but excessive levels of natural conditioning agents such as alkalies in the dust. Ash from wood combustion is a good example of this. Where possible, process changes will usually help -- such as changing the fuel sulfur level or improving combustion efficiency to minimize the carbon content of the ash.

Conditioning Agents

Conditioning agents have also been used to correct low resistivity problems. One of the better known applications is ammonia injection into gas streams containing large quantities of SO_2/SO_3. Although tests have indicated (as in the high resistivity cases) that no apparent change occurs in resistivity, the agglomeration characteristic of particles on the plates changes and results in improved particle-to-particle cohesion. This helps to reduce the reentrainment problems that characterize low resistivity dusts. In addition, the ammonia may react with flue gas constituents to form fine ammonium salt particles; for example, ammonia combines with the SO_3 to form ammonium sulfate, and with CO to form ammonium carbonate. These fine particles increase the space charge and cause higher operating voltages and the application of higher forces to the particles at the plates.

The resistivity-related problems associated with ESPs have been well studied in recent years, and the prediction of and design considerations for resistivity have become more precise. Some combination of corrective actions is usually available to the plant that experiences a high or low resistivity problem. Each corrective measure has both an economic and practical consideration, and site-specific factors will determine which options are chosen.

T-R Sectionalization and Power

The remaining alternatives for correcting resistivity problems are more complex and more expensive. One of these is to retrofit additional ESP plate area to improve collection efficiency. This may entail the use of new designs, such as wide plate spacing. Retrofitting also may be difficult because of equipment placement and space limitations. Another alternative is to change the T-R sectionalization and perhaps to use low-power (secondary current limit) T-Rs and/or pulse energization.

The use of low power T-Rs and increased sectionalization also can improve performance by matching electrical capabilities to the demands of high resistivity. The most common alternative, however, is the use of chemical conditioning to modify the resistivity characteristics of the particulate or to reduce their effects on ESP performance.

In addition to proprietary chemical additives, typical chemical additives include SO_3, sulfuric acid, ammonia, and soluble alkali salts. Most rely on the chemical additive to improve the surface conduction mechanism of charge transfer and to lower the effective resistivity of the particulate. One exception to this is ammonia injection, which generally has little effect on dust resistivity, but may alter the electrical characteristics of the gas stream and the agglomerating characteristics of the ash on the plates. The effects are often unpredictable. This has been used more on low resistivity problems caused by high sulfur fuels. The quantities of chemical additives required and their effectiveness vary.

504.2 CORRECTIVE ACTIONS FOR DUST ACCUMULATION PROBLEMS

The most common cause of excessive dust accumulation on the electrodes is failure of the rapper-control system. Unless there is reason to suspect otherwise (e.g., known high resistivity potential or other indications of hopper pluggage), this should be one of the first areas checked if power input into the ESP decreases markedly. This problem is relatively easy to rectify.

Rapper Failures

Rapper failures may involve individual rappers, entire electrical fields, or the entire ESP. Although isolated rapper failures are usually not severe, they can affect the performance of the field they are serving. An easy approach to this problem is to have a few rappers assembled in the spare parts inventory for quick change-out when a malfunctioning rapper is found. When the malfunctioning rapper is disassembled and the defective component(s) replaced, the rebuilt rapper is then placed into the spare parts inventory.

The reasons for individual rapper failure depends on the rapper type. Magnetic-impulse, gravity-impact (MIGI) rappers may fail because of a short in the coil that lifts the rapper. Electric vibrators may fail because the proper air gap or sealing from the elements has not been maintained. Air-activated or pneumatic rappers often fail because water and/or oil enter the compressed air lines or because the solenoid fails to open the air supply line. Internal falling-hammer failures are more difficult to diagnose if the problems are inside the ESP. Problems such as misalignment of hammers with the anvils or a broken drive shaft usually cannot be diagnosed until the ESP is shut down for an internal inspection. Two of the more common problems with internal rappers are failure of the drive motor and failure of the gear reduction system.

Failure of the rappers serving one field of the ESP can usually be traced to the rapper control cabinet(s). Depending on the design, rapper controls are usually in separate cabinets for both the discharge electrodes and the collection plates. The collection plate controls may be further separated into individual cabinets for each field, or one cabinet may contain the controls for all the rappers on the ESP. If a failure at the control cabinet is the suspected cause for excessive dust buildup in the ESP, the first check should be to see if the power is on and that the fuse or circuit breaker has not been opened. A check should be made to ascertain proper operation of the switch and drive on some older systems that use rotary switches to activate the rappers.

After these basic checks, corrective actions become more complicated and dependent on the rapper manufacturer. The manufacturer usually outlines specific procedures for testing the rapper control circuit boards for failed components. These are beyond the scope of this manual; however, some interesting problems have been noted, particularly with MIGI rappers. The most interesting problem is the continual failure of the rapper control card components. Failure or lack of a diode to protect the transistors from charges carried back to the rapper control cabinet may contribute to the failure. Most but not all rappers are constructed with internal diodes for such protection. When no protection is provided for the cards, there is a potential for many card failures. Another problem involves the electrical arrangement of the rappers in such a manner that failure of one disables all of them. In some cases, this arrangement makes it nearly impossible to find the rapper that malfunctioned. Rappers wired in this manner should be rewired for ease of maintenance, i.e., in parallel instead of in series.

Rapping Frequency

When dust buildup is suspected and the rappers are in good operating order, the available options are to increase rapping frequency or to increase rapping intensity. Both options have certain advantages and disadvantages. Not all rapper control systems can control both frequency and intensity; however, if possible, an increase in rapping frequency is a good first choice (usually the only choice with internal rappers). Many dusts respond well to this, whether the buildup is caused by an increase in dust generation rate or an increase in resistivity. Rapping more frequently reduces the maximum dust layer thickness if sufficient rapping energy is provided.

Rapping Intensity

If an increase in rapping frequency does not improve electrical characteristics after several hours, an increase in intensity may be required. Large increases in rapping energy should be avoided, however. Increases probably should not exceed 50 percent. Some ESPs are designed to withstand only limited rapping forces before damage to the ESP can occur. High-resistivity or sticky dusts usually require increased rapping intensity. If increasing rapping frequency and intensity fail to remove the dust (particularly high-resistivity dusts), a procedure called "power-off" rapping may help. Removing the power from the field to be rapped greatly diminishes the electric forces holding the dust to the plate and may allow the dust to be removed. Usually only one field at a time is rapped with the power off and for a period of 15 minutes to an hour. The power is usually turned off manually, althrough an automatic power-off option is available from some manufacturers on new T-R/rapper control systems. The disadvantage of this procedure is that it may increase the emissions from the ESP.

Shutdown

When all other measures fail to remove the material from the plates or discharge electrodes, the remaining option is to shut the ESP down and wash it out. This option should be kept at a minimum, as it may increase corrosion. This procedure generally will remove the dust from the internal components; however, in some instances the dust layer must be scraped off, a time-consuming and difficult task.

All of the procedures discussed assume that the ESP has sufficient rapping capability, including appropriate rapping force, and that the design does not assign the cleaning of too much plate area to a single rapper. One aspect of the rigid-electrode or rigid-frame designs (of utility ESPs with large plates) that tends to overcome dust accumulation problems is the use of at least one internal rapper per plate. Two to four plates per rapper are the standard on smaller rigid-frame ESPs. In weighted-wire designs, the rapper may have to cover from two to six plates; however, the rapping intensity of these rappers is controllable. Additional rappers can be retrofitted to an ESP to reduce the plate area per rapper and to increase rapping effectiveness.

504.3 CORRECTIVE ACTIONS FOR WIRE BREAKAGE

Keep Records

The general approach to correcting a wire breakage problem is to find the broken wire in the field and clip it out during the next convenient outage. Most of the time a broken wire is not replaced, and the bottle weight is removed to prevent its falling into the hopper. If wire failure is random, as many as 10 percent of the wires can be removed without significantly deteriorating ESP performance. Records should be kept of wire failure locations and dates to ascertain that they are indeed random.

If a pattern of failures begins to show, it should be interpreted as a symptom of some other problem. For example, a pattern showing that wires are failing in the ESP or at the same location on the wire (top, bottom, middle, etc.) should alert plant personnel that the problems go beyond just a broken wire.

Several wire failure mechanisms were discussed earlier in this section. The most common is failure of the wire either at a plate/wire misalignment point or where the wire passes the edge of the plates in the collecting field (end effect). Localized corrosion due to inleakage may be reduced by reducing inleakage (sealing access doors, maintaining duct integrity). Crimping of the wires, which can cause excessive sparking or corrosion, may be a manufacturing and/or installation defect. In these instances, these wires may have to be replaced.

The problems with misalignment and end effects can be solved in various ways. When a misalignment problem is localized within an area of the ESP (e.g., because of three or four warped plates), plant personnel may opt to remove the wires in the gas lanes. This will usually improve operating voltages and current and prevent excessive wire breakage. This option should not be exercised unless the plates cannot be straightened. The danger of this procedure is that it may allow dust-laden gas to pass through the ESP essentially untreated if other adjacent upstream and downstream fields happen to be deenergized. To avoid this possibility, some plants weld plate steel into position to block the flow of gas down these lanes and force it to flow down other lanes. When the entire field is misaligned due to plate warpage or guide misalignment, clipping wires is not a sound solution.

Wire Shrouds

Two methods are used to minimize excessive sparking due to end effects at the plates. The first is the use of wire shrouds that extend 6 to 18 inches from both ends of the wires. These shrouds are approximately 3/8 to 1/2 inch in diameter and generate corona only at very high operating voltages. In addition, it takes a long time for the spark to cause electrical erosion of the large effective wire diameter. The second method (designed into new ESPs) is the use of rounded plates at the top and bottom rather than sharp edges with an effective diameter equivalent to the plate thickness. In the new designs, the ends are rounded and approximately 2 to 3 inches in diameter. By reducing the distortion of the electrical field at the end of the plates, this new design reduces sparking. This latter change is difficult to retrofit into an existing ESP, but wires with shrouds can be used to replace most unshrouded wires and should be considered when wholesale wire replacement is scheduled.

Rounded Plates

When the 10 percent random wire failure rate has been reached or if more than 5 to 10 wires in any gas lane have been removed (depending upon ESP design), replacement of broken wires should be considered. If the wire breakage rate appears to be on the increase, however, it may be advisable to replace all the wires. During replacement, care must be taken to avoid crossing wires and causing premature failure due to wear.

504.4 CORRECTIVE ACTIONS FOR HOPPER PLUGGAGE

When hopper pluggage is detected, immediate action should be taken to clear the pluggage and empty the hopper. Maintenance personnel should give this problem highest priority, as failure to respond can significantly reduce long-term ESP performance.

Foreign Objects

Hopper pluggage can be caused by foreign objects such as wires or weights, cooling of the dust in the hopper or hopper throat, an undersized dust-conveying system, or the introduction of moisture into the hopper. Hoppers should be equipped with level detectors. They also should be insulated, and in many cases should be equipped with heaters. Rod-out capabilities are necessary, and a method of removing the hopper throat for emptying would be advantageous.

If a hopper is plugged but not filled, one appropriate action is to place the T-R controller for the field(s) above the plugged hopper in the manual mode to reduce the collection rate until the hopper is ready to be cleared. If the hopper is completely filled and the T-R has not tripped automatically, it should be turned off until the hopper has been cleared. The T-R must be deenergized while clearing of the hopper is in progress, to prevent electrocution of maintenance personnel.

500 TROUBLESHOOTING

When ESPs are overdesigned in terms of sectionalization and plate area, their hoppers and dust removal system are often underdesigned. Because their inlet fields collect more material than was planned, the overload causes the hoppers to plug while the outlet fields remain virtually empty. When this occurs, the dust removal from the gas stream can be spread more evenly in the ESP by reducing power input to the fields that are plugged. This permanent reduction in power may change the pattern within the ESP and adversely affect its performance. The ESP must be adequately sized for this option to be exercised. (Note: maldistribution of the gas stream can produce similar effects.)

Bridges

The use of vibrators on the hopper does not necessarily enhance the flowing properties of all dusts. In fact, it can worsen the situation by compacting the dust in the hopper. Striking the hopper, however, can dislodge "bridges" of dust attached to the hopper walls. The hopper wall or throat should not be struck, as the impact may cause damage that provides a future site for hopper bridging and pluggage; rather, reinforced strike plates should be installed for the occasional strike that may be needed.

Stones

The use of hopper "stones" to fluidize the dust can provide mixed results. Placed near the bottom of the hopper, they may contribute to the pluggage problem by closing off open areas in the hopper. These stones, which are similar to those used to aerate aquariums, but much larger, must be supplied with dry, heated air. A high-quality dryer is needed to remove the moisture and oil, and the air must be heated so it will not cool the dust in the hoppers.

Excessive cooling of the dust can cause problems. Condensation of acid or moisture can solidify some dusts, make others extremely sticky, and simply cause some not to flow well. Hopper heaters and insulation usually help keep the hoppers warm. Pluggage of hoppers on the windward or north side of the ESP in the winter can cause excessive amounts of heat to be carried away from the hoppers. In many cases this can be corrected by constructing a windbreak or enclosing the hoppers to reduce cooling effects.

Baffles

Finally, hoppers are usually sloped so as to provide good flowing characteristics. Gas sneakage baffles that project too far into the hopper sometimes contribute to the bridging problem. These baffles are desirable for preventing gas sneakage, and if bridging occurs, they can be shortened to minimize hopper pluggage.

If dust is suspected to have reached the plates and wires during an incident of hopper pluggage, a gas-load V-I curve should be generated to determine that no buildup, clinkers, or serious misalignment has occured in the fields. The T-R should then be returned to normal operation. When maintenance personnel clear the hoppers or open a hopper access foor, care must be taken to avoid electrocution or being overcome by the dust or gas stream.

Gas-Load

504.5 CORRECTIVE ACTIONS FOR MISALIGNMENT

Shutdown

An outage is necessary in order to correct misalignment in an ESP. Depending upon the extent of the misalignment, solutions range from simple application of heat and pressure to complete removal and replacement of the plates or discharge guide frames. As the repairs become more complex, the time required for correction also increases.

Failure to support, or compression, or stand-off insulators for the discharge electrode system can cause widespread misalignment within the ESP between the wires and plates. Hopper pluggage can also shift the lower guide frame and contribute to the failure of standoff insulators. As indicated previously, reliable hopper level indicators are a means of avoiding misalignment due to hopper pluggage. The replacement of the insulators and subsequent realignment is relatively easy and straightforward if none of the internal ESP components have been bent.

Misalignment due to bent plates, bent wire, or bent rigid frames is more difficult to correct. If the point of misalignment is near the edge of the field, adequate access may be available to attempt corrective actions; however, misalignment that is halfway into the field, where access is poor, may be difficult to correct.

Plate straightening can be attempted by one of several methods. The simplest is to bend the plate back into shape by use of a small hydraulic press. Sometimes heating with a torch is alternated with water quenching to relieve the stress on the plate while returning it to position. Another option (for small sections of plate) is to remove the warped section with a cutting torch and replace it. (Note: some plants merely cut away the warped section without replacing it. This is poor practice.) This approach is generally limited to a section of plate edge small enough to fit through the access doors. Central portions of the plate area are generally not accessible. Care must be taken to remove all burrs and to smooth the plate before operation is begun again.

Some plants have tried replacement of plate sections or panels in ESP designs where the plate is composed of individual sections approximately 18 inches wide. In this time-consuming procedure, the plate sections to be removed are unclipped and detached from the plate hangers and guide. If enough room is available in the ESP for the panel and lifting equipment, the new panel or panels are brought in through the access door and the plate is reassembled. In major rebuilding involving replacement oflarge portions of plate area, it is often easier to remove the roof of the ESP and to replace the plates with a crane.

Bent wire frames or lower guide frames often cause the wires to slacken and bow towards the plates. Distorted lower guide frames are often difficult to straighten and may have to be replaced; however, if the distortion is not too severe and only a few wires are slack, it may be worthwhile just to remove those wires. On rigid-frame designs, space limitations often dictate the extent of straightening that can be done to the discharge frame. The wires may be tightened by crimping them in the direction of gas flow. This tightens the wires and prevents bowing towards the plate. It can also increase sparking and damage to the wire. Because the wires in rigid frame ESPs are usually of a larger diameter, however, it is usually an acceptable trade-off.

In summary, if a general misalignment is caused by a shift in guide frame components, it usually can be corrected by realigning the frame. Plate warpage or wire frame warpage may be more difficult to correct, however. All ESPs have a certain freedom of motion to allow expansion and contraction. Checks should be made to see that this freedom is maintained and that there is no binding before the other approaches to correcting misalignment are considered.

504.6 CORRECTIVE ACTIONS FOR INLEAKAGE

The corrective action for inleakage is straightforward. Unless the design calls for the admission of ambient air for a specific purpose, any spot of inleakage should be sealed. Such an approach reduces the total gas volume to the ESPs can help to prevent acid dewpoint problems, contributes to more stable operation, and can enhance the gas distribution into the ESP.

Double Doors

Check Gaskets

All access doors should remain sealed during routine operation. This includes hopper access doors and penthouse doors. On newer designs, the use of double doors for sealing and insulating has become popular to minimize in-leakage and door corrosion. Gaskets should be checked periodically and replaced if damaged. Any corrosion around doors or expansion joints should be corrected immediately, as the corrosion rate tends to accelerate around these points.

A routine check of oxygen content and temperature in combustion flue gas is a useful indicator of inleakage. Such checks should be conducted along the ductwork from the process exit to the ESP outlet. (Note: a system under positive pressure generally does not have inleakage problems, but outleakage may contribute to fugitive emissions and exterior corrosion.) Any sudden increase in O_2 in a nonstratified gas stream indicates inleakage. This is usually accompanied by a corresponding decrease in temperature. The point of inleakage will usually be between the sampling locations where the change in O_2 occurred. The causes can be a broken or worn seal, a hole in the ductwork, or sampling ports that were left open. Appropriate action should be taken.

504.7 SUMMARY

Because problems are often site-and design-specific, extensive coverage of corrective action is not possible. Nevertheless, the major problems have been addressed. As previously stated, it is useful to understand the nature and magnitude of the effects of various ESP problems. Before selecting any corrective action, one must first determine the cause of the problem so that the proper corrective action is chosen rather than one that merely treats the symptom. Long-term ESP performance usually benefits from this approach.

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This section is written primarily for plant personnel at a facility with an electrostatic precipitator (ESP).

Preventive Maintenance

The maintenance discussed in the following sections is preventive maintenance. Its goal is to maintain the long term performance of the ESP and to minimize the failure of various components that affect ESP performance. An important aspect of preventive maintenance is routine, scheduled inspections of the ESP, both internally and externally. These inspections include daily or shift inspections, weekly inspections, monthly or quarterly inspections, and outage inspections (the only time internal inspections are performed).

Appendix D

Sample maintenance checklists are provided in appendix D.

Depending on the unit's operating history and the manufacturer's recommendations, internal inspections can be performed quarterly, semiannually, or annually. As the time interval increases, the amount of action required usually increases. Daily and weekly inspections may require checks of operating parameters and general operating conditions, whereas monthly or quarterly inspections require specific actions regardless of performance of the ESP.

Safety Procedures

A discussion on safety procedures and the key-interlock system is included in section 605, which covers internal inspections.

601 DAILY INSPECTION AND MAINTENANCE

A portion of the the daily inspection or shift inspection may be conducted as part of a parameter monitoring and recordkeeping plan. The purpose of routine and frequent inspections is to identify the existence of any operating problems before they develop into more serious failures.

Electrical Readings

The instrumentation available on most ESPs provides the first indicator of performance problems. Process operating data and ESP corona power levels should be recorded, as described in section 501 of this manual. These values should be compared against baseline values or normal values established for the source. Once this is done, some simple external checks should be performed, unless operating values of a field or fields show considerable change. Should this occur, the remainder of the inspection should concentrate on identifying at

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least one of the possible causes of the change. The Troubleshooting section in this manual details how to do this by using electrical readings. If the electrical readings recorded are normal, the following checks should be made on the ESP.

Opacity

Opacity readings should be made. Although most regulations require the data to be reported on the basis of an aggregate of three minutes in any one hour, the ability to observe the magnitude and frequency of individual rapping spikes is beneficial in optimizing ESP performance. Any changes in these values from baseline conditions are important because they may indicate the need for further investigation and maintenance.

Hopper Temperature

The operation of the dust discharge system should be checked. All conveyors, airlocks, valves, and other associated equipment should be operating for continuous removal of the collected dust. If hopper heaters are used, the current levels at each hopper will indicate whether these heaters are operating. Hopper throats should be warm to the touch; a cold hopper throat may indicate that the hopper is plugged. If a vacuum system is used, vacuum charts may provide a useful indication of proper hopper emptying. The operation of indicator level alarm systems should also be checked. All access doors in the hopper area should also be checked by looking or listening for dust inleakage or discharge.

Rappers

The operation of the rappers should be checked. Although it is not necessary to check the operation of every rapper, almost every rapper should activate. The purpose of this check is to determine if the entire field or the entire ESP rapping system is out of service. If possible, individual rappers out of service should be identified so that appropriate maintenance can be performed. If monitored, the frequency and intensity of rapping should also be noted.

Sparking

Other checks of the ESP externals include listening for sparking or arcing in the T-R high voltage bus duct, localized sparking (usually reflected by T-R readings), and audible inleakage around all other access hatches on the ESP. Although these problems will generally affect ESP performance, the effect will not be long-term if they are corrected in a timely manner.

602 WEEKLY INSPECTION AND MAINTENANCE

Review Daily Data

The best way to start a weekly inspection is with a brief review of the daily or shift inspection data. This review should attempt to identify any apparent trends in the key operating parameters and to determine whether a change is needed in some operating practice or maintenance procedure. In addition, this review should confirm that all requested or required maintenance has been completed satisfactorily or has been scheduled in a timely manner. Lastly, a week is generally sufficient time for a change in operation (e.g., rapping intensity and timing, some process changes, gas-conditioning systems operation) to surface in ESP performance, even though longer periods may be necessary to establish the trend.

After reviewing the previous week's operating data and comparing it against normal or baseline values, the inspector should make a physical check of the ESP, including daily or shift inspection activities. The items covered in the following paragraphs also should be checked.

T-R Cabinets

When the T-R readings are obtained, the cabinet air filters should be checked and cleaned or replaced. Although some cabinets may not be equipped with cooling fans, the air intakes and vents should be filtered to keep the cabinet internals clean. Dust buildup on circuit boards and heat sinks can cause excessive heat buildup and electrical problems within the control circuitry. It is generally recommended that T-R control cabinets be placed in a temperature-controlled, clean environment to minimize failure of contoller circuitry. Integrated circuits cannot withstand the high temperatures that may accompany a hot, dirty environment.

Test Rappers

Rapper operation should be checked more thoroughly during the weekly inspection. Each rapper or rapper system should activate, and those that do not should be scheduled for repair or replacement. Proper operation of internal falling-hammer systems is more difficult to ascertain, but rapper drive motors should operate when activated by the rapper controller. Rapper settings for intensity, duration, and frequency should be recorded. Changes in these settings should be made as necessary to optimize performance. These new settings should also be recorded.

While on the roof of the ESP, the inspector should note the operating temperature and oil level in the high-voltage transformer. Generally, indicators on the

Purge Air System

transformer will show the desired operating range. In addition, the operation of any insulator purge air and heating systems should be checked. Air filters on the purge air system should be checked and cleaned or replaced. Failure of the purge air system may cause fouling or condensation on insulation surfaces, which can result in electrical tracking or breakage of the insulator. In negative pressure systems, if insulators can be contaminated by variations in the induced draft (ID) fan operation, or during startups, the insulator pressurization and heating system should be checked more often than weekly.

All access hatches should be checked for inleakage. This can be done by listening and by feeling around the hatch while it is locked shut. If inleakage occurs, the door gasket, and possibly the door, should be replaced. Inleakage can cause excessive sparking in localized areas, corrosion, reentrainment of particulates, and wire breakage due to reduced temperatures.

603 MONTHLY OR QUARTERLY INSPECTIONS

Whether a monthly or quarterly inspection is required depends on the manufacturer's recommendations and on selected site-specific criteria; however, all of the recommended procedures should be followed at least quarterly.

The control cabinets for T-R sets and rappers should be vacuumed to remove any accumulated dust and dirt inside the cabinet. The exterior of the cabinets for rapper controls should be checked for proper seal of the door gaskets. If allowed to deteriorate, these gaskets will permit water and dust to enter the cabinet and may result in failure of the rapper control cabinet. In addition, all switch contacts within the rapper control cabinet should be cleaned.

All rappers should be checked for proper operation. Checks should include proper striking of anvils for magnetic-impulse, gravity-impact (MIGI) rappers, proper lift, and energy transfer. Pneumatic systems and vibrators should be adjusted as necessary to transfer the proper amount of rapping energy to the collection or discharge systems. Although ESPs equipped with falling- hammer rappers are more difficult to check, gear-reduction drive systems should be checked for proper sealing. The boots may fall over a period of time and allow water and cool air to enter the ESP. This can cause corrosion or unit operating problems due to inleakage.

Hopper Alarm Systems

Hopper heaters should be checked for proper operation if the ESP is so equipped. Hopper-level alarm systems should be checked for proper operation.

Calibrate ESP Instrumentation

The ESP's instrumentation should be checked and calibrated. This includes all voltage and current meters. The primary voltage and current meters should be calibrated as alternating current root mean square (AC RMS) values, whereas the secondary voltage and current meters should be calibrated against a direct current (DC) power supply. The transmissometer should also be cleaned and realigned during this inspection.

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604 SEMIANNUAL INSPECTION AND MAINTENANCE

Grounding Straps

Depending on the operation, the semiannual inspection may correspond with a maintenance shutdown or outage, and internal inspections are then conducted. Considerations for an internal inspection are discussed under the annual inspecton section.

Key - Interlocks

Transformer Oil

In addition to the recommended procedures for quarterly and weekly inspection and maintenance, semiannual procedures should include the lubrication of all door hinges and closure mechanisms, the cleaning and lubrication (with graphite) of key interlocks, and a check of all ground connections (grounding straps and sampling and testing transformer oil for maintenance of dielectric strength.

605 ANNUAL INSPECTION

The process and its ESP generally should be shut down at least once a year for a more complete inspection, including a check of internal conditions. Adherence to established safety and confined-area entry procedures cannot be overemphasized.

Safety First

The safety of plant personnel during all aspects of ESP operation and maintenance, and of regulatory agency personnel during inspections, is of ultimate importance. Areas of concern include electrical shock hazard, confined area entry (oxygen deficiency and toxic gases), hazardous materials (dust, metals, etc.), chemical burns, eye injury, and normal industrial safety concerns such as moving equipment. In ESPs, many of these dangers are of concern simultaneously, and can result in serious injuries to personnel. With proper planning, safety equipment, and established procedures, operation, maintenance, and inspections can be performed safely with reduced risk of injury.

Safety key-interlocks should never be bypassed to enter the ESP.

605.1 KEY-INTERLOCK SYSTEM

Electrical shock is the greatest concern in the operation of an ESP. During the particle-charging process, high DC voltages are generated by the transformer-rectifier (T-R) set and transferred to the discharge electrodes. All portions of the electrical system outside of the ESP shell must be insulated or isolated from potential contact. All access points to the electrical distribution system must be closed and bolted or key-interlocked to limit inadvertent access to the system.

In addition, a clear, legible sign must be attached to each component indicating the nature of the hazard. Areas requiring warning signs include T-R set control cabinets, high-voltage conduit, the T-R set, shell access doors (inlet/outlet plenums, top access doors, insulator compartments, and penthouse), hopper access doors, and rapper control cabinets.

Key-interlocks are used to assure that the ESP has been deenergized before personnel enter the ESP or electrical distribution system. The key-interlock system consists of the use of keys in a number of sequenced steps that must be followed to deenergize and permit ESP components to be opened. As these

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systems are designed for each individual ESP setup, they vary from unit to unit. For specific directions, the inspector should refer to the manufacturer's literature.

Main Circuit Breakers

Most key-interlock systems are set up so that the user begins with the main circuit breakers on the T-R set control panels. Opening the circuit breakers releases a mechanical interlock that allows keys contained in the circuit breaker mechanism to be turned and removed. Rotation of the keys locks the breaker in the open system and prevents its operation. One key is released for each T-R set control cabinet.

Closed

The keys from the control cabinet are inserted into the interlock on the T-R set grounding switches; one key is used for each T-R set. Insertion and rotation of the key allows the T-R set grounding switch to be moved from the operating (closed position) to a ground position. The switch cannot normally be interlocked in an open position; it must be fully closed to a ground position, which completes the electrical circuit from the deenergized transformer to ground.

Ground

This position ensures safety by disconnection the T-R set from the electrical distribution system, and by grounding the T-R set. Any attempt to energize the T-R set would result in an immediate short circuit to ground.

When the T-R set ground switch has been positioned, a second set of keys located on the T-R set ground switch may be rotated, which locks the switch in position. Removal of these keys ensures that the switch cannot be moved into the open or operating position.

Keys from the T-R set ground switch may be placed into the master key interlocks in the transfer block. After keys from all ground switches are in place, keys located in the transfer block can be rotated. Rotation of these keys locks the T-R set switch keys in place and prevents their removal. The transfer block keys may be removed and used to open access doors on the ESP.

The number of keys needed depends on the number of T-R sets and access doors on the individual units. Maintenance of the key-interlock system is critical in any safety program. Locks are equipped with weather-tight covers (caps, lock boxes, etc.), and each cover must be replaced after removal, and maintained in that position. Locks should be lubricated (graphite only, no oils), and preventive maintenance should be performed as necessary to ensure clean, trouble-free operation.

Under no circumstances should the key-interlock system be bypassed or short-circuited to gain access to the ESP without proper and complete deenergization of the unit. If special studies or analyses require access to an energized unit, a complete safety analyses, including proper safety procedures, must be established for each occurrence.

Following the key-interlock procedure provides two points of electrical safety:

Mechanical Lockout

1 The T-R set main breaker (mechanical lockout);

Electrical Isolation

2 The T-R switch ground switch (electrical isolation and ground).

Many companies further isolate the unit for positive assurance of grounding of the electrical distribution system. Access doors are removed from the electrical conduit between the T-R set and wire frame, and the lead wires are disconnected from the wire frame.

A potential for nonisolation of the T-R set ground switch exists in many older designs that use an immersed switch in the transformer fluids. In these designs, the switch arm mechanically connected to the knife switch with set screws, clamps, etc., can become loosened with use and will not close fully. Because the switch is not visible, its position cannot be verified. As a further safety measure, many companies use a permanent ground switch or wire that must be thrown or placed in position on the high-voltage bushing in the penthouse or insulation enclosure before further access is possible. Placement of this device on an energized T-R results in an immediate short and a T-R trip.

Window

More modern designs require an air switch on the T-R set, and the contacts are visible through a window. This ensures that the T-R is grounded and allows visual verification of the switch position.

Grounding Straps

Grounding straps bolted to the ESP shell must be provided at each access point to prevent potential electrical hazards. The strap is attached to the electrical discharge system nearest the entry point and clamped in place prior to entry. The corona wire-plate system acts like a capacitor and discharges slowly after a T-R set trip. To prevent potential shock, the ground strap should be connected to the plate system and discharge electrode system.

Ground straps should be checked routinely to ensure their continuity, and the insulated attachment devices (fiberglass or wooden handles) should be inspected for damage. If exposed to weather, wooden handles can deteriorate; and if exposed to dust and metal particles, they can become conductive because the dust and metal particles become embedded in the surface.

It is possible to lock up and energize an ESP with personnel inside. The design of he key-interlock system only requires the following of a stop-by-step procedure to energize a unit. To prevent the possible closure of the unit with personnel inside, a tag or personnel lock system is required. Central Operation should be notified whenever anyone enters the unit. Tags should be placed on the main breaker, T-R set switch, and entry door advising that personnel are working inside. Entry should never be made alone without proper notification and proper tagging of the access door. If a procedure is established for use of a two-man buddy system (one man on the outside), that person cannot leave this position without being replaced.

Buddy System

605.2 SHUTDOWN PROCEDURES

As process load decreases the ESP generally can be deenergized one field at a time. As in startup, the selection of the first field to be deenergized can be made from either the inlet or outlet field. The inlet field is the preferred choice. As each field is deenergized, so is the electrical field that held the dust to the plates. Having the next field in line energized reduces the quantity of emissions.

When the process is shut down, all remaining T-Rs should be deenergized. The rappers and hopper evacuation system should be allowed to run from several hours to twenty four hours after process shutdown, to remove as much dust as possible from the ESP.

605.3 CONFINED-AREA ENTRY

A confined space is an enclosure in which dangerous air contamination cannot be prevented or removed by natural ventilation through some opening of the space. Access to the enclosed area also may be restricted so that it is difficult for personnel to escape or to be rescued. Common examples of confined spaces are storage tanks, tank cars, or vats. Depressed areas like trenches, sumps or wells also may have poor ventilation and msy be condidered confined spaces. An electrostatic precipitator (ESP) falls under the general definition of confined space, and so requires special procedures and precautions with regard to entry. Potential dangers presented by confined space fall into three categories: oxygen deficiency, explosion, and exposure to toxic chemicals and agents.

Oxygen Deficiency

Oxygen deficiency is the most common hazard. Any gas introduced into a confined space displaces the atmosphere and reduces the oxygen content below the normal value of 20.8 percent. Out-gassing of combustible gases (methane, hydrogen sulfide,organic vapors and others) from collected particulate can result in local pockets with reduced oxygen levels. Further, application of the ESP to combustion sources (utility boilers, industrial boilers, cement kilns, recovery boilers, incinerators) produces an atmosphere that is extremely low in oxygen content (2 to 10 percent). Purging if the unit during cooling does not always completely replace the flue gases with ambient air, and local pockets may remain.

Explosions

Explosive atmospheres can be created in confined spaces by the evaporation of volatile components or improper purging of the ESP when the process is shut down. Three elements are necessary to initiate an explosion: oxygen, a flammable gas or vapor, and an ignition source. A flammable atmosphere is defined as one in which a gas concentration is between two extremes: the lower explosive limit (LEL) and the upper explosive limit (UEL). A mixture of gas and oxygen in a concentration between these two values can explode if a source of ignition is present. With regard to ESP inspection and maintenance, explosive gases normally consist of methane, hydrogen, carbon monoxide, and mixed organic vapors. The gases most commonly present at ESP shutdown are carbon monoxide and methane.

Possible sources of ignition include cigarettes, matches, welding, cutting torches, and grinding equipment. Sparks can also be generated by static electricity and electric discharge through grounding straps. The best means of preventing explosion is to dilute the flammable gas below the LEL by ventilation. It is not safe to assume that a source of ignition can be eliminated and to allow work to continue in a potentially explosive atmosphere.

Work in a confined area may release flammable gases that, once released, can increase in concentration. Constant ventilation should be provided to maintain the concentration below LEL.

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Because many vapors are heavier than air, pockets of flammable gases also may develop. An effective monitoring program checks concentrations at multiple locations and times during the exposure period.

Toxic Chemicals

Depending on the application of the ESP, collected dust may contain toxic chemicals or harmful physical agents. These compounds may exist in the system or be created as a result of operations in the confined area. Inhalation, ingestion, or skin contact can have adverse health effects. Most agents have threshold limit doses below which harmful effects do not occur. Exposure above these threshold doses can cause acute or chronic symptoms, depending on the compound.

A quantitative assessment of each compound and the threshold dose levels must be made before anyine enters the ESP. Typical toxic chemicals or species in the ESP environment include carbon monoxide (CO), hydrogen sulfide (H_2S), total reduced sulfur (TRS) gases, arsenic, cadmium, beryllium, lead, alkali, and acids. If repair work is being conducted, organic solvents, zinc, or cadmium also may be present.

Entry may be permitted within certain limitations provided the person is equipped with appropriate approved respiratory protection. An assessment of the hazard, concentration, permissible exposure, and protective equipment must be made before anybody is allowed to enter the equipment.

Each facility must establish a confined-space entry policy that includes recognition of the hazards, atmospheric testing and analysis, ventilation requirements, selection and use of protective equipment, training and education of personnel, and administrative procedures.

Hazard Recognition

An important component of the policy is recognition of the potential hazard, which requires complete knowledge of the industrial process and wash area. A cursory examination cannot prevent serious deficiencies; a detailed analysis is recommended.

The second policy component involves air monitoring. An initial certification of gaseous concentrations must be made before entry is permitted. This certification must be made by a qualified safety officer with properly calibrated and maintained equipment. In general, a permit to enter (with a time limit) may be issued and displayed at the point of entry. Assuming that oxygen and gas levels do not change with time can be dangerous; an effective program should include periodic reevaluations of concentrations after initial entry.

Air Monitoring

Gas monitoring should be conducted to determine percent oxygen, percent lower explosive limit, hydrocarbon concentration, and carbon momoxide levels. If hydrogen sulfide or other toxic gases are suspected, additional analyses may be conducted with detection tubes or continuous gas samplers. The use of continuous gas samplers with an audible alarm is recommended. The initial measurements should be performed according to the following suggested measures:

1 The ESP to be entered should be emptied, purged, cleaned, and ventilated to the maximum extent possible. All entry ports should be opened to facilitate mixing. All electrical and mechanical equipment must be completely isolated by closing dampers, using guillotine dampers, or installing blanks.

2 A gas tester should check the vessel's oxygen content, explosivity, and a toxic chemical concentration by first sampling all entry ports and then sampling inside the space with probes (while he remains outside). Caution should be used when testing for combustible gases, as many meters need an oxygen level close to ambient levels to operate correctly. This is one reason that the space should be purged and vented before testing. Voids, sub-enclosures, and other areas where pockets of gas could collect should also be tested.

3 When initial gas test results show that the space has sufficient oxygen, the gas tester can enter the space and complete the initial testing by examining areas inaccessible from outside the shell. The tester should wear an air supplied positive pressure respirator during these measurements. Special care should be taken to test all breathing zone areas.

4 If the results of the initial tests show that a flammable atmosphere still exists, additional purging and ventilation are required to lower the concentration to ten percent of the LEL before entry may be permitted.

5 If testing shows an oxygen deficient atmosphere or toxic concentrations, all personnel entering the space must use an appropriate air supplied respirator.

After the initial gas testing has been performed, dust, mists, fumes, and any other chemical agents present should be evaluated by either an industrial hygienist or a trained technician. The results will indicate if additional control measures are necessary. Physical agents such as noise, heat, and radiation must also be evaluated, and if any are present, the appropriate measures (such as providing ear protection or rotating employees) should be instigated.

The specified respiratory protection should be based on the hazard assessment.

Eye Protection

Additionally, eye protection is necessary to prevent dust from entering the eyes. Goggle-type protection is generally not effective because of the inability of the frames to form a tight seal against the worker's face. Effective eye protection consists of full-face protection, a snorkling mask, or eye goggles.

Hearing devices should also be worn when personnel enter the ESP, because the metal walls tend to reflect and amplify sound energy.

Skin Protection

Skin contact with dust collected in an ESP can result in burns or irritation. The dust may be acidic, alkaline, hygroscopic, or abrasive. Workers can limit skin contact area and thus prevent potential irritation by wearing long-sleeved shirts and gloves during internal inspections.

605.4 HOPPER ENTRY

Hoppers present special safety hazards. Although access to an ESP hopper does not put one in direct contact with the electrical system, a broken electrode wire represents a potential electrical shock hazard.

It is generally recommended that hopper doors be interlocked and that the doors be opened only after the unit has been deenergized. For economic reasons, however, many companies use padlocks instead of a key-interlock system. In principle, this practice is as safe as the key-interlock system if proper safety procedures are followed. Workers often remove the lock and open hopper doors prematurely to cool a unit quickly or to clear hopper pluggage. The main danger in opening the doors is the discharge of hot ash impounded in the hopper.

In the opening of hopper doors, the inspectors must take care to ensure that no accumulation of collected dust is impounded behind the inner door. Before hopper doors are opened, an internal inspection must also be made from the top of the collecting surfaces to be certain no buildup is present in the corners of the unit or in the valleys of the pyramidal hoppers. Dust that has accumulated in valleys or corners may break loose during entry into the hopper and cause minor injury. In some cases, more serious injury or suffocation can result from dust falling on and burying personnel.

Dust Accumulation

Entry into hoppers for entry other than maintenance should be avoided. Maintenance should first be attempted from outside the hopper. If the hopper must be entered, steps should be taken to dislodge and discharge dust before such entry. This can be accomplished by mechanical vibration (vibrators, hammers), poking, prodding, or air lancing. Complete removal can be accomplished by washing with a high pressure water hose.

Removal of accumulated dust should be made from the lower catwalk at the bottom of the ESP; it must not be attempted from inside the hopper. Care should be taken to ensure that any dust accumulation in the inlet and outlet plenums (nozzles) is removed. This material can become dislodged, move en masse into the inlet or outlet field hoppers, and completely fill the hopper. Finally, before the hopper doors are opened, the inlet plenum should be checked, and any dust should be moved into the hopper for discharge.

Hopper doors should not be opened during ESP operation because hot ash could overflow onto the operator. This ash is very fluid, and it could quickly engulf and severely burn a person. Even after prolonged storage, ash temperatures can be in the 300 °F to 400 °F range for cold-side ESPs, and in the 700 °F to 800 °F range for hot-side units.

Safety Chains

All hopper doors should be equipped with safety chains or double latches to prevent complete opening upon release. This can slow the loss of ash in the event of accidental opening of a full hopper.

Most hopper inner doors have design features, that, if properly used, will ensure that no door is opened when dust is impounded behind it. First, a pipe coupling with a plug that can be removed should be installed in the door; this would allow visual verification. Second, a pressure-type latch should be used that allows a portion of the door seal to be released to create a gap between the door and sealing jam. This partial release would allow accumulated dust to flow out and indicate a partially full hopper without the possibility of the door opening fully.

One way to determine the fullness of a hopper is to strike the access door with a hammer. If the hopper is empty, this will produce a resounding ring, indicating that there is no material against the inside surface; if the hopper is full, the blow will produce a dull thud.

A further warning regarding hopper entry involves the use of handgrips and footholds in the hopper. Because of the possible dust buildup on protruding objects, manufacturers have purposely avoided the use of handholds and footholds in hopper interiors. The steep valley angles and and dust layer create the potential for a fall and injury for persons entering the door. Because of the angles and small door openings, abrasion and back injuries top the potential injury list. Outside access equipment (scaffolds, ladders, handholds) should be installed to minimize the awkwardness of hopper door entry.

Radiation Source

If nuclear hopper level detectors are used, the beam (which is a radiation source) should be shielded from the outside prior to entry. This shielding should be part of the interlock system for the doors.

Hopper evacuation systems (screws, drag chains, agitators) should not be operated when personnel are inside the hopper area or in an area from which they could fall inside the hoppers.

605.5 INTERNAL INSPECTION

Before anyone enters the ESP, an air-load check of each field is recommended. The record of this can be compared with air-load tests performed after the scheduled maintenance is completed. Using these tests can help direct attention to problem areas with the unit, and can also show whether the necessary maintenance has been conducted.

With the key interlock system, the actual opening of the ESP can be relatively time-consuming. When these procedures have been completed and the doors opened, the grounding straps should be attached to a wire inside the access door. This establishes a positive ground to bleed away any voltage retained by the plates (the ESP behaves like a large capacitor) and to prevent energization of a field if, for some unforseen reason, the interlock system should fail. These grounding straps should be used for each field in the ESP.

It is generally recommended that the ESP be cooled and purged prior to entry. However, with proper safety equipment and precautions, inspections can be performed without this extra step. In any case, the confined work area should be sampled and evaluated for oxygen deficiencies and the presence of toxic substances and combustible materials before anyone enters the ESP. Once inside, personnel should use continuous monitors with alarms, or at least routinely monitor the internal conditions of the ESP.

The inspection practices following assume entry into the ESP through the side of the unit, at the bottom of the plates.

The initial inspection of a collection and discharge electrode system should be used to observe several items. The first is whether there is a buildup of material on the surfaces. Generally, 1/8 to 1/4 inch of material will remain on the plate even in its clean, "rapped-down" condition. Too much buildup can lead to both energization and gas distribution problems within the ESP and is indicative of poor or ineffective rapping. Clean metal conditions may indicate low resistivity, high gas velocity, or too much rapping. Buildup on wires should be minimal.

The nature, extent, and locations of any buildups within the ESP should be noted. While checking for buildups, the alignment of the wires and weights should also be checked. Any bowing or skewing resulting in more than 1/2 inch out of alignment is usually visible, and its location should be noted for corrective action. A misaligned ESP usually causes reduced voltage and power input, and increased sparking.

Broken Wires

Checks for broken wires are usually conducted on fields where short-circuits are found. The broken wires should be clipped and removed, as should any loose bottle weights. The location of the broken wire, and which part of the wire failed, should be recorded as part of the permanent record. Generally, wires are not replaced individually as they fail because, provided they occur randomly, wire failures typically do not greatly affect the performance of an ESP. Wires used should be the proper length. Sometimes wires are crossed to shorten them so they will fit within the upper and lower guide frame. However, the rubbing of the crossed wires during operation will result in wire failure.

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Alignment

The upper and lower discharge guide frame assembly should be aligned so that equal spacing is maintained, not only from the top to the bottom of the plate, but also from the leading edge to the trailing edge of the plates. The frames should be level in both parallel and perpendicular planes to the gas flow. Frames that are not level, or twisted frames may cause excessive tension on some wires and insufficient tension on others (slack wires). When checking the upper discharge frame, the upper support beams should be checked for excessive dust buildup. These buildups will sometimes cause intermittent high sparking in the upper section of the ESP, which reduces collection efficiency. Additional baffles may be necessary to prevent such buildups.

All insulators should be checked and cleaned to remove dust accumulation. They should also be checked for any evidence of insulator tracking. The inside of the large support bushing insulators at the top of the ESP, and the discharge rapper insulators should be inspected. Any insulators that are broken, chipped, cracked, or glaze-damaged should be removed and replaced.

Hoppers should be emptied, and all buildup removed. Some buildup may occur in the corners of in the upper portion where the hoppr joins the ESP housing. In flat-bottom ESPs such as used in conjunction with recovery boilers, the space between agitators should be checked and any buildups should be removed. All hopper level detectors should be checked and repaired as necessary, and defective hopper heaters should be replaced. Since nuclear hopper level detectors can expose maintenance personnel to radiation, the built-in shields should be put in place before any personnel enter the hopper. All dust discharge valves should be checked and cleaned and repaired as necessary. These valves should be maintained to prevent any inleakage of air into the hopper, which can aggravate hopper pluggage and cause dust reentrainment.

The interior of the ESP should be inspected for corrosion of the shell, plates and wires. Localized areas of corrosion may indicate points of inleakage, which cause temperatures to fall below the acid dewpoint. Sonic testing can be utilized to determine the thickness of the shell. Besides reducing the strength of materials, corrosion can cause scaling of the metal components, which interferes with the clearance within the ESP and reduces performance. Corrosion and excessive dust in the penthouse or insulator housing may indicate that insufficient purge air is being supplied to the insulator housing, which will cause condensation of flue gas in this area.

Rapper rod connections or anvils for the discharge system and the plates should be checked. Loose, broken or bent connections should be repaired to allow rapping force to be transferred efficiently into the ESP.

T-Rs

Transformer-rectifier sets (T-Rs) should be checked and cleaned. All contacts should be removed, cleaned and adjusted. All electrical connections should be checked for proper tightness. Loose connections and dirty contacts can cause electrical erosion and wasted energy, and may lead to failure of the T-R. The high voltage line, bushings and insulators should be checked and cleaned. Surge arrestors should be checked and replaced if necessary. The high-voltage bus duct should be checked for dust buildup and corrosion, which could lead to grounding of the transformer secondary. All leaks in the bus duct should be repaired during the assembly to keep moisture and inleakage to a minimum. All insulators contained within the bus duct should be checked and replaced as necessary. Tightness of the connections for the high-voltage bus duct should be checked. Transformer switchgear should be cleaned and adjusted for proper contact.

The inlet and outlet distribution system should be checked for pluggage and dust buildup. This includes the inlet and outlet ductwork. Buildups should be removed. If buildups are substantial and recurrent, some modificactions may be needed to minimize them.

Door gaskets should be checked for a proper seal. It may be worthwhile to replace these gaskets annually or biannually to reduce inleakage. Expansion joint seals should also be checked and changed as necessary. Failure of expansion joints can lead to excessive inleakage and increased corrosion.

Water Washdown

Water washdown of the ESP is generally not recommended unless a dust is present that will adversely affect ESP performance after startup, and there is no other way of removing the material from the plates. Water-washing an ESP can accelerate corrosion and cause rust and scaling, which interfere with the electrical performance of the ESP. The ESP must be dry before operations resume.

At the completion of the outage, an air-load test of the ESP should be performed. This will indicate whether the maintenance is in fact completed, and will serve as a record of readiness for operation.

605.6 STARTUP PROCEDURES

Startup practices greatly affect the subsequent operation of an ESP and may be as important to performance as daily operating checks and maintenance practices. Of major concern during the startup of ESPs on most processes are corrosion and buildup of material on plates, wires and insulators. These can severely limit ESP performance. For some processes, the potential hazard of fire and explosion resulting from unstable operations is a primary concern. Startup practices should be geared to address these potential problems.

When preparing for startup of an ESP, ground devices should be removed so that the transformer-rectifier (T-R) can operate. The persons responsible for checking the ESP should determine that it is free of all foreign materials. After this is completed, the ESP may be closed up and the keys for the interlock system should be returned to their appropriate locations.

Air-Load Test

Next, an air-load test should be conducted for each T-R set, and for each bus section if time allows this. The air-load test is conducted under ambient conditions with little or no air flow during energization of each section. The test result should be an air-load curve for each T-R, and will become part of the permanent record for the unit.

Points of interest for an air-load test are: the voltage at corona initiation; the shape of the voltage/current curve; and the voltage and current values when sparking occurs. Primary voltage readings can be made if secondary voltage meters are not installed on the unit.

Fields with similar geometry should have similar voltage-current (V-I) curves. Any major deviation between curves, or between a curve and its reference curve may indicate an internal problem. The diagnosis of problems using air-load curves is presented in section 500 of this manual. It is very important to resolve such problems before starting up the precipitator.

Heaters

Insulator heaters, hopper heaters and purge-air systems should be turned on two to twelve hours before startup. Also, even if the ESP is not energized, the rapper system and hopper evacuation system should be in operation during startup to remove any dust that has settled. While gas loads and particulate loadings are well below normal operating loads, the ESP can function as an effective settling chamber. It can remove the large diameter particulates entering it. Increasing the rapping intensity should help dislodge any wet (from condensation) or sticky particulate that has collected in the wires or plates. Rapping intensity can be returned to normal several hours after operating temperature is reached.

When and how much of the ESP should be energized is a much-debated topic in many applications. Many believe that energization should not be attempted until the moisture dewpoint has been exceeded for several hours, and some like to wait until the acid dewpoint temperature has been surpassed, to avoid excess sparking and to minimize buildup on the ESP internals. Newer power supplies are often able to energize an ESP with little or no sparking, while older controllers are best operated during startup on manual control at a setting below the spark threshold.

Explosion

Sparking during startup can be very problematic. Unstable combustion in the process served by an ESP can lead to unburned carbon, hydrocarbons, and carbon monoxide in the precipitator. A fire or an explosion could occur under such circumstances. Apart from the immediate danger to personnel, the performance capability of the ESP could be significantly reduced.

It is usually unnecessary to energize the entire ESP during startup. Opacity limitations can usually be met with the unit only partially energized. Recommendations vary as to which of the fields, the first or the last, should be energized first. As the particulate-load and the gas-load increase, additional T-R sets can then be brought on-line, placed in automatic control, and optimized for power input and spark rate.

606 WET PRECIPITATORS

This section describes the operation and maintenance related facets of typical wet ESP installations. Wet precipitators are made in different configurations; these are described in section 304.2. They are less widely applied than the more conventional devices, and there is little published information on operating and maintenance practices. When the components of a wet precipitator are similar to those of a dry precipitator, the troubleshooting and maintenance procedures outlined in sections 500 and 600 are considered applicable.

Heaters and blowers are usually energized first during normal operation. The spray system is always activated just before the high-voltage system is energized. Gas flow is monitored by damper. Operators must monitor the pH of the water at the waste discharge.

Because inspection and maintenance of wet ESPs are highly specific to the system, operators should follow closely the instructions provided by the manufacturer. Since precipitators operate with very high voltage, precautions must be exercised to ground the precipitator internals properly. The gas flow must be stopped and the unit cooled to a safe temperature before any person enters the precipitator. Protective apparatus such as a respirator may be needed.

The inspector should familiarize himself with the general inspection and maintenance practices that the company should be following; these are briefly outlined below.

606.1 MECHANICAL MAINTENANCE

All internal components should be checked for alignment, dust buildup, tightness of bolts, structural soundness of welds, and structural integrity of cross bracing and other support members. Since the support insulators perform such a vital function in electrostatic precipitation, the structural support end of the high-voltage insulator in the high-voltage housing must be thoroughly inspected for cracks, chips, or other defects.

606.2 WATER SYSTEMS

Pipes

Valves

Nozzles

All pumps, internal spray nozzles, and related valving and piping should be checked. Nozzles are subject to plugging and therefore should be routinely disassembled, cleaned, and/or replaced as necessary. Other required checks include the main supply pumps for water pressure, all pipe joints for leaks, and all couplings for tightness. Nozzle orientation should be checked and adjusted as necessary to maintain the intended spray pattern.

606.3 ELECTRICAL SYSTEM

Inspection should include the high-voltage control panel, heater and blower control panel, high-voltage insulators, heater system thermostats, T-R sets, and all related electrical connections. When components of wet precipitator systems are similar to those of dry units, many of the inspection and maintenance practices outlined earlier will apply.

606.4 SCHEDULE

Table 606.1 summarizes a typical maintenance schedule, as recommended by the manufacturer and given to the plant at the time of wet ESP installation.

Table 606.1 Manufacturers Suggested Maintenance Schedule for Wet ESPs [7]

Component	Interval	Maintenance Procedure
Key Interlocks	Yearly	Check for corrosion and clean.
	Yearly	Check that key fits and turns easily; lubricate as required.
	Yearly	Check proper positioning of dust caps.
Ducts and dampers	Quarterly	Open and close dampers; operation must be smooth and positive.
	Quarterly	Check ducts for an accumulation of dust; clean as necessary.
Precipitator	Quarterly	Check condition of paint; retouch as necessary.
	Quarterly	Clean corroded areas inside casing thoroughly.
Access doors	Quarterly	Check seal for tightness.
	Quarterly	Inspect gaskets and replace if damaged.
Collecting plates and discharge electrodes	Quarterly	Clean thoroughly.
	Quarterly	Check hanging fixtures for damage.
Baffles	Quarterly	Clean thoroughly.
Hopper	Quarterly	Clean thoroughly.
	Quarterly	Check drain lines for clogging.
High-voltage system:		
T-R set	Quarterly	Check oil level; add oil if required.
	Yearly	Check and tighten electrical connections.
	Yearly	Replace damaged wiring.
	Yearly	Clean output bushing.
	Yearly	Check output bushing for cracks or damage.
	Yearly	Check continuity of ground wire.
	Yearly	Check grounding switch for positive action.

Table 606.1 (con

Component	Interval	Maintenance Procedure
High-voltage system:		
Insulators	Quarterly	Clean thoroughly and dry.
	Quarterly	Check for cracks or other damage.
	Quarterly	Tighten electrical conections.
Control panel	Quarterly	Check panel switches for positive action.
	Yearly	Check and tighten electrical connections.
	Yearly	Check condition of internal components.
	Yearly	Clean inside and outside of panel.
	Yearly	Check condition of fuses.
Heater and boiler system:		
Heaters	Yearly	Check continuity of each shipment.
	Yearly	Check and tighten electrical connections.
	Yearly	Check clearance around insulator.
Blower	Weekly	Replace air filters.
	Yearly	Check condition of blower and blower motors.
Control panel	Yearly	Check panel switch for positive action.
	Yearly	Check and tighten electrical connections.
	Yearly	Check condition of internal components.
	Yearly	Clean inside and outside of panel.
	Yearly	Check condition of fuses.
Spray system	Weekly	Check pressure at nozzle head.
	Weekly	Check spray pattern.
Operating checks	Daily	Check pH of water system.
	Daily	Visually check indicators for burned-out lamps.
	Daily	Check input and output meters for correct readings.
Dampers	Monthly	Lubricate operators.

APPENDIX A

Appendix A contains two rules presented as samples of particulate matter emission-limiting rules. The rules shown here are South Coast AQMD Rules 404 (Particulate Matter - Concentration) and 405 (Solid Particulate Matter - Weight).

(Adopted May 7, 1976)(Amended October 5, 1979)
(Amended February 7, 1986)

RULE 404. PARTICULATE MATTER - CONCENTRATION

(a) A person shall not discharge into the atmosphere from any source, particulate matter in excess of the concentration at standard conditions, shown in Table 404(a).
Where the volume discharged is between figures listed in the table, the exact concentration permitted to be discharged shall be determined by linear interpolation.
The provisions of this subsection shall not apply to any equipment completed and put into service before July 1, 1976 in the Palo Verde and Joshua Tree areas.
Before July 1, 1983, liquid sulfur compounds shall not be included as particulate matter discharged from petroleum coke calciners.

(b) A person shall not discharge into the atmosphere from any source, particulate matter in excess of 450 milligrams per cubic meter (0.196 grain per cubic foot) in discharged gas calculated as dry gas at standard conditions.
The provisions of this subsection shall apply only to any equipment completed and put into service before July 1, 1976 in the Palo Verde and Joshua Tree areas.

(c) The provisions of this rule shall not apply to emissions resulting from the combustion of liquid or gaseous fuels in steam generators or gas turbines.

(d) For the purposes of this rule, emissions shall be averaged over one complete cycle of operation or one hour, whichever is the lesser time period.

(e) The provisions of this rule shall not apply to the use of equipment which complies with the emission limits specified in Rule 1112.1.

TABLE 404(a)

Volume Discharged Calculated as Dry Gas At Standard Conditions		Maximum Concentration of Particulate Matter Allowed in Discharged Gas Calculated as Dry Gas at Standard Conditions		Volume Discharged Calculated as Dry Gas At Standard Conditions		Maximum Concentration of Particulate Matter Allowed in Discharged Gas Calculated as Dry Gas at Standard Conditions	
Cubic Meters Per Minute	Cubic Feet Per Minute	Milligrams Per Cubic Meter	Grains Per Cubic Foot	Cubic Meters Per Minute	Cubic Feet Per Minute	Milligrams Per Cubic Meter	Grains Per Cubic Foot
25 or less	883 or less	450	0.196	900	31780	118	0.0515
30	1059	420	.183	1000	35310	113	.0493
35	1236	397	.173	1100	38850	109	.0476
40	1413	377	.165	1200	42380	106	.0463
45	1589	361	.158	1300	45910	102	.0445
50	1766	347	.152	1400	49440	100	.0437
60	2119	324	.141	1500	52970	97	.0424
70	2472	306	.134	1750	61800	92	.0402
80	2825	291	.127	2000	70630	87	.0380
90	3178	279	.122	2250	79460	83	.0362
100	3531	267	.117	2500	88290	80	.0349
125	4414	246	.107	3000	105900	75	.0327
150	5297	230	.100	4000	141300	67	.0293
175	6180	217	.0947	5000	176600	62	.0271
200	7063	206	.0900	6000	211900	58	.0253
250	8829	190	.0830	8000	282500	52	.0227
300	10590	177	.0773	10000	353100	48	.0210
350	12360	167	.0730	15000	529700	41	.0179
400	14130	159	.0694	20000	706300	37	.0162
450	15890	152	.0664	25000	882900	34	.0148
500	17660	146	.0637	30000	1059000	32	.0140
600	21190	137	.0598	40000	1413000	28	.0122
700	24720	129	.0563	50000	1766000	26	.0114
800	28250	123	.0537	70000 or more	2472000 or more	23	.010[illegible]

(Adopted May 7, 1976)(Amended February 7, 1986)

RULE 405. SOLID PARTICULATE MATTER - WEIGHT

(a) A person shall not discharge into the atmosphere from any source, solid particulate matter including lead and lead compounds in excess of the rate shown in Table 405(a).
Where the process weight per hour is between figures listed in the table, the exact weight of permitted discharge shall be determined by linear interpolation.
The provisions of this subsection shall not apply to any equipment completed and put into service before July 1, 1976, in the Palo Verde and Joshua Tree areas.

(b) A person shall not discharge into the atmosphere in any one hour from any source, solid particulate matter including lead and lead compounds in excess of 0.23 kilogram (0.5 pound) per 907 kilograms (2000 pounds) of process weight.
For the purposes of this subsection only, process air shall be considered to be a material introduced into the process when calculating process weight.
The provisions of this subsection shall apply only to equipment completed and put into service before July 1, 1976 in the Palo Verde and Joshua Tree areas.

(c) For the purposes of this rule, emissions shall be averaged over one complete cycle of operation or one hour, whichever is the lesser time period.

(d) The provisions of this rule shall not apply to the use of equipment which complies with the emission limits specified in Rule 1112.1.

TABLE 405(a)

Process Weight Per Hour		Maximum Discharge Rate Allowed for Solid Particulate Matter (Aggregate Discharged From All points of Process)		Process Weight Per Hour		Maximum Discharge Rate Allowed for Solid Particulate Matter (Aggregate Discharged From All points of Process)	
Kilograms Per Hour	Pounds Per Hour	Kilograms Per Hour	Pounds Per Hour	Kilograms Per Hour	Pounds Per Hour	Kilograms Per Hour	Pounds Per Hour
100 or less	220 or less	0.450	0.99	9000	19840	5.308	11.7
150	331	0.585	1.29	10000	22050	5.440	12.0
200	441	0.703	1.55	12500	27560	5.732	12.6
250	551	0.804	1.77	15000	33070	5.982	13.2
300	661	0.897	1.98	17500	38580	6.202	13.7
350	772	0.983	2.17	20000	44090	6.399	14.1
400	882	1.063	2.34	25000	55120	6.743	14.9
450	992	1.138	2.51	30000	66140	7.037	15.5
500	1102	1.209	2.67	35000	77160	7.296	16.1
600	1323	1.340	2.95	40000	88180	7.527	16.6
700	1543	1.461	3.22	45000	99210	7.738	17.1
800	1764	1.573	3.47	50000	110200	7.931	17.5
900	1984	1.678	3.70	60000	132300	8.277	18.2
1000	2205	1.777	3.92	70000	154300	8.582	18.9
1250	2756	2.003	4.42	80000	176400	8.854	19.5
1500	3307	2.206	4.86	90000	198400	9.102	20.1
1750	3858	2.392	5.27	100000	220500	9.329	20.6
2000	4409	2.563	5.65	125000	275600	9.830	21.7
2250	4960	2.723	6.00	150000	330700	10.26	22.6
2500	5512	2.874	6.34	175000	385800	10.64	23.5
2750	6063	3.016	6.65	200000	440900	10.97	24.2
3000	6614	3.151	6.95	225000	496000	11.28	24.9
3250	7165	3.280	7.23	250000	551200	11.56	25.5
3500	7716	3.404	7.50	275000	606300	11.82	26.1
4000	8818	3.637	8.02	300000	661400	12.07	26.6
4500	9921	3.855	8.50	325000	716500	12.30	27.1
5000	11020	4.059	8.95	350000	771600	12.51	27.6
6000	13230	4.434	9.78	400000	881800	12.91	28.5
7000	15430	4.775	10.5	450000	992100	13.27	29.3
8000	17640	5.089	11.2	500000 or more	1102000 or more	13.60	30.0

APPENDIX B

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APPENDIX C

Appendix C contains checklists useful for inspection and troubleshooting purposes. Included are:

Inspection Checklist, to be used by district inspectors as a guideline in drawing up their own ESP inspection checksheets;

Electrostatic Precipitator Baseline Comparison [3] checklists, which are useful in identifying problems;

and Summary of Problems Associated With ESPs [23] tables, which should be useful in diagnosing causes of ESP malfunctions.

Inspection Checklist

This checklist is designed to serve as an example of the information gathering process that a regulatory agency inspector may follow in order to make a compliance determination. District inspectors may wish to use this checklist as a guide in drawing up their own electrostatic precipitator inspection sheets.

Step 1	Stack Effluent
Step 2	Continuous Emission Monitors
Step 3	Fan Operating Parameters
Step 4	ESP Performance Analysis from Electrical Readings
Step 5	External Inspection
Step 6	Ash Handling Procedures
Step 7	Process Operating Conditions
Step 8	Internal Inspection
Step 9	Review Operating Records

VISIBLE EMISSION OBSERVATION FORM

No.

COMPANY NAME	
STREET ADDRESS	
CITY	STATE / ZIP
PHONE (KEY CONTACT)	SOURCE ID NUMBER
PROCESS EQUIPMENT	OPERATING MODE
CONTROL EQUIPMENT	OPERATING MODE
DESCRIBE EMISSION POINT	
HEIGHT ABOVE GROUND LEVEL	HEIGHT RELATIVE TO OBSERVER Start End
DISTANCE FROM OBSERVER Start End	DIRECTION FROM OBSERVER Start End
DESCRIBE EMISSIONS Start End	
EMISSION COLOR Start End	IF WATER DROPLET PLUME Attached ☐ Detached ☐
POINT IN THE PLUME AT WHICH OPACITY WAS DETERMINED Start End	
DESCRIBE PLUME BACKGROUND Start End	
BACKGROUND COLOR Start End	SKY CONDITIONS Start End
WIND SPEED Start End	WIND DIRECTION Start End
AMBIENT TEMP Start End	WET BULB TEMP / RH, percent

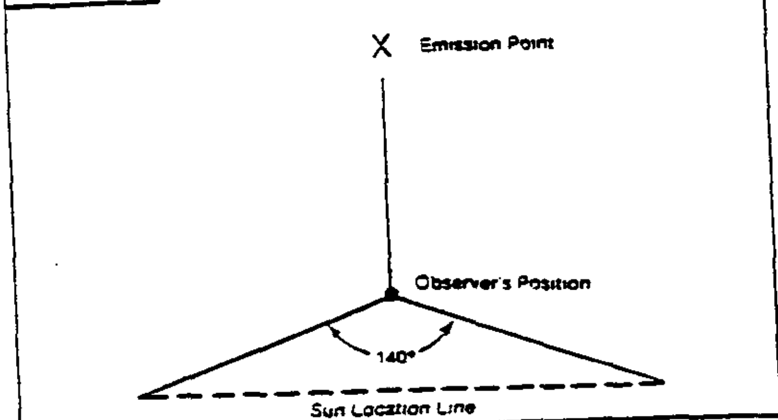
SOURCE LAYOUT SKETCH

Draw North Arrow

Stack with Plume

Sun

Wind



ADDITIONAL INFORMATION

OBSERVATION DATE	START TIME	END TIME

SEC / MIN	0	15	30	45	COMMENTS
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					

OBSERVER'S NAME (PRINT)	
OBSERVER'S SIGNATURE	DATE
ORGANIZATION	
CERTIFIED BY	DATE
CONTINUED ON VEO FORM NUMBER	

Step 2 Continuous Emission Monitors

Opacity monitor readings

Operating: Yes____ No____
Minimum, %_________
Average, %__________
Maximum, %_________

Spikes (Characterize frequency, duration, intensity)

____
____
____

Calibration spikes (Characterize levels, frequency)

____
____
____

Calibrated according to required schedule: Yes____ No____

Gas temperature

____
____

Comments

____
____
____
____
____

Step 3 Fan Operating Parameters

	Parameter	Baseline	Present	Change, %
1.	Increase in total static pressure across fan	______	______	________
2.	Electric current drawn by fan motor	______	______	________
3.	Fan wheel rotation speed (rpm)	______	______	________
4.	Gas temperature at fan inlet	______	______	________
5.	Flue gas oxygen level at fan inlet	______	______	________

A. Baseline and Present values of Parameters 1, 2, 3 differ by less than 10%: Yes____ No____
B. Baseline and Present values for differ by less than 20 °F: Yes____ No____

(If answers to questions A and B are both 'Yes' then mass emissions have probably not changed significantly.)

Mass emissions may have increased significantly: Yes____ No____

(Increased oxygen levels in flue gas indicate air inleakage.)
(Reduced gas temperature and increased electric current indicate air inleakage.)

Air inleakage may be significant: Yes____ No____

Generally, the inspector performs Steps 4 onwards to confirm the evaluations of Steps 1 - 3. The inspector may skip over to Step 9 if the answers to the following 3 questions are 'Yes.'

1. Gas flowrate has increased or decreased substantially: Yes____ No____
   Basis for determination: Opacity - Steps 1, 2
   Gas temperature - Steps 2, 3
   System Pressure Drop - Step 3
   Fan Motor Current - Step 3

2. Mass loading has increased: Yes____ No____
   Basis for determination: Opacity - Steps 1, 2
   System Pressure Drop - Step 3

3. Particle outlet size distribution has changed: Yes____ No____
   Basis for determination: Opacity - Steps 1, 2
   Color of plume - Step 1

Step 4 ESP Performance Analysis from Electrical Readings

Compare V, A and sparkrate values for all T-Rs with baseline values.

Note all inoperative meters ____

____

____

T-R Set No.	Present Primary Voltage	Baseline Primary Voltage	Present Primary Current	Baseline Primary Current	Present Spark Rate	Baseline Spark Rate	Present Sec. Voltage	Baseline Sec. Voltage	Present Sec. Current	Baseline Sec. Current

Any bus sections not operating at design levels?

____

____

____

ESP Layout

Inspector should identify T-R sets that power bus sections.

Chamber A		Chamber B	

Chamber C		Chamber D	

Evaluation of ESP Performance By Corona Power Method

Electrical Parameters

1. What is K_1 for this facility?________
2. What is C (Coefficient of Proportionality) for this facility?________
   C = (emission level) / (penetration)
   Use values from a previous source test
3. What is the volume flowrate for each chamber?________
4. Is particulate resistivity moderate to high? Yes____ No____
5. Is power input to ESP less than 1000W per 1000 ACFM? Yes____ No____

If the answers to either questions 4 or 5 above are 'No,' you cannot determine ESP performance by the Corona Power method.

Calculate Corona Power

If the ESP has secondary voltage and secondary current meters, fill out Table A. If not, use primary voltage and primary current values and fill out Table B.

Table A

Chamber A

T-R Set #	Secondary Current mA	Secondary Voltage kV	Corona Power mA x kV
		P_c= Total Corona Power	

Chamber B

T-R Set #	Secondary Current mA	Secondary Voltage kV	Corona Power mA x kV
		P_c= Total Corona Power	

Table B

Chamber A

T-R Set #	Primary Current mA	Primary Voltage kV	Corona Power mA x kV x 0.75
		P_c= Total Corona Power	

Chamber B

T-R Set #	Primary Current mA	Primary Voltage kV	Corona Power mA x kV x 0.75
		P_c= Total Corona Power	

Do permit conditions require a minimum power level to the ESP or to each chamber?

___

___

___

$P_t = e^{-.06K_1(P_c/V)}$

$E.L. = P_t \times C$

Chamber	Corona Power P_c	Gas Flow Rate	Specific Corona Power	K_1	Penetration P_t	C	Emission Level
A							
B							
C							
D							

Combined calculated emission level values for all chambers ducted to the same stack: ___________
Allowable maximum emission level for this facility: _______________

Is calculated E.L. value greater than allowable maximum emission level? Yes____ No____

If yes, a source test should be ordered to determine emission level more exactly.

Comments:

____

____

____

____

____

Step 5 External Inspection

Insulators:

Evidence of tracking: Yes____ No____

____

____

____

Corrosion of insulator compartment: Yes____ No____

____

____

____

Fan working properly: Yes____ No____

____

____

____

Air filters for compartment clogged: Yes____ No____

____

____

____

Heater working: Yes____ No____

____

____

____

Rappers all operating: ____

____

____

	Air Infiltration		Comments	Corrosion		Comments
	Yes	No		Yes	No	
Access doors Top access hatches Expansion joints Rapper shafts						

Fugitive emissions from ESP or ductwork: Yes____ No____

Comments ____

____

Step 6 Ash Handling Procedures

Vibrators: Yes____ No____
Operating: Yes____ No____

Heaters: Yes____ No____
Operating: Yes____ No____

Level indicators / alarms: Yes____ No____
Operating: Yes____ No____

Transport equipment: Screws____ Pneumatic____ Other____
Operating: Yes____ No____

Evidence of inleakage

____
____
____
____
____

Comments

____
____
____
____
____

Step 7 Process Operating Conditions

	Baseline or Permitted Values	Present Values
Gas flow rate	______	______
Excess air	______	______
Gas temperature	______	______
Pressure drop across ESP	______	______
Moisture content	______	______
Soot blowing intervals	______	______
Flue gas analysis (% O_2, CO_2, ...)	______	______
______	______	______
______	______	______
______	______	______

Comments ____

____

____

____

Step 8 Internal Inspection

For information to be gathered when conducting an internal inspection, see checklist provided for operators of ESPs for their annual internal inspection, in appendix D of CAP ESP manual.

Step 9 Review Operating Records

Recordkeeping Requirements	Records Kept Satisfactorily
Opacity meter	Yes____ No____ Comments____________
ESP inlet gas temperature	Yes____ No____ Comments____________
ESP outlet gas temperature	Yes____ No____ Comments____________
Pressure drop across ESP	Yes____ No____ Comments____________
____________________	Yes____ No____ Comments____________
____________________	Yes____ No____ Comments____________
____________________	Yes____ No____ Comments____________
____________________	Yes____ No____ Comments____________
____________________	Yes____ No____ Comments____________

If frequent breakdowns have occurred, can the source show maintenance records to demonstrate they have made good faith efforts to treat causes of operating problems? ____________

Inspection findings: ____________

Compliance determination: ____________

Maintenance recommendations: ____________

Electrostatic Precipitator Baseline Comparison [3]

Possible Operating Problems	Average Baseline (Specify Value)	Observed (Specify Value)	Location [a]	Abnormal (Check)
I. ELECTRICAL				
A. Particle Resistivity				
1. Peak voltage low (down 5-10 kV)			E	
2. Rapping intensity (increased)			E	
3. Temp. changed (± 50 °F)			E	
4. Spark rate increased (± 50 sparks/min)			E	
5. Opacity high			E	
B. Transformer-Rectifier set problems				
1. No secondary current	N/A		E	
2. No penthouse purge	N/A	N/A	E	
3. Voltage zero, current high	N/A	N/A	E	
4. Opacity high			E	
C. Insulator failure				
1. Peak voltage low			E	
2. Penthouse purge (not used)	N/A	N/A	E	
3. Pentouse temp. high (± 20 °F)			E	
4. Opacity high			E	
5. Cracks visible	N/A	N/A	I	

[a] E is external, I is internal.

ESP Baseline Comparison (contd.)

Possible Operating Problems	Average Baseline (Specify Value)	Observed (Specify Value)	Location [a]	Abnormal (Check)
I. ELECTRICAL (continued)				
D. Broken discharge wires				
1. Deposits on wires	N/A	N/A	I	
2. Violent matter fluctuating	N/A	N/A	E	
3. Hopper level indicator not used	N/A	N/A	E	
4. Spark rate high (± 50 sparks/ min.)			E	
5. Opacity high			E	
6. Broken discharge wires	N/A	N/A	I	
II. GAS FLOW				
A. Excessive velocity				
1. Flow rate high			E	
2. Voltages high, currents, low			E	
3. Opacity high			E	
B. Nonuniform distribution				
1. Flow rate increased			E	
2. Secondary currents nonparallel	N/A	N/A	E	
3. Hopper level differences on parallel branches			I	
4. Rappers on distribution plates not used			E or I	

[a] E is external, I is internal.

ESP Baseline Comparison (contd.)

Possible Operating Problems	Average Baseline (Specify Value)	Observed (Specify Value)	Location [a]	Abnormal (Check)
III. MECHANICAL				
A. Rapper Problems				
1. Puffs visible	N/A	N/A	E	
2. Peak voltage changes, secondary current constant			E	
3. Spark rate changed			E	
4. Dust sticky	N/A	N/A	E	
B. Hopper solids removal				
1. Broken discharge wires	N/A	N/A	I	
2. Mass loading probably increased	N/A	N/A	E	
3. Nonuniform gas distribution	N/A	N/A	E	
4. Hoppers not emptied continuously	N/A	N/A	E	
5. Level indicaors not used	N/A	N/A	E	
6. Heaters not used	N/A	N/A	E	
7. Vibrators not used	N/A	N/A	E	
8. Hoppers not insulated	N/A	N/A	E	
9. Corrosion around outlet valves	N/A	N/A	I	
10. Hopper slope < 60°	N/A	N/A	E	
11. Hoppers full or bridged	N/A	N/A	I	
C. Collection plate warpage and misalignment				
1. Change in air load	N/A	N/A	E	
2. Repeated hopper overflow	N/A	N/A	E or I	
3. AIr inleakage	N/A	N/A	E	
4. Misalignment visible	N/A	N/A	I	

[a] E is external, I is internal.

ESP Baseline Comparison (contd.)

Possible Operating Problems	Average Baseline (Specify Value)	Observed (Specify Value)	Location [a]	Abnormal (Check)
IV. EFFLUENT CHARACTERISTICS				
A. Mass loading increases				
1. Opacity high	______	______	E	____
2. Inlet section, secondary currents, low	______	______	E	____
3. Hopper unloading frequency increased	______	______	E	____

[a] E is external, I is internal.

Summary of Problems Associated With ESPs[23]

Malfunction	Cause	Effect on ESP Efficiency	CorrectiveAction	Preventive Measures
Poor electrode alignment	Poor design Ash buildup on frame and hoppers Poor gas flow	Can drastically affect performance and lower efficiency	Realign electrodes. Correct gas flow.	Check hoppers frequently for proper operation
Broken electrodes	Wire not rapped clean, causes an arc that embrittles and burns through the wire	Reduction in efficiency due to reduced power input, bus section unavailability	Replace electrode.	Boiler problems: check for insufficient excess air, insufficient pressure reading on gages, fouled screen tubes, and fouled air preheater
	Clinkered wire. Causes: poor flow area, distribution through unit is uneven; excess free carbon due to excess air above combustion requirements or fan capacity insufficient for demand required; wires not properly centered; ash buildup resulting in bent frame, same as above; clinker bridges the plates and wire shorts out; ash buildup, pushes bottle weight up causing sag in the wire; "J" hooks have improper clearances to the hanging wire; bottle weight hangs up during cooling causing a buck-led wire; and ash buildup on bottle weight to the frame forms a clinker and burns off the wire.			Inspect hoppers; check electrodes frequently for wear; inspect rappers fre-quently.

Summary of Problems Associated With ESPs (contd.)

Malfunction	Cause	Effect on ESP Efficiency	Corrective Action	Preventive Measures
Distorted or skewed electrode plates	Ash buildup in hoppers Gas flow irregularities High temperatures	Reduced efficiency	Repair or replace plates. Correct gas flow.	Check hoppersfrequently for proper operation; check electrode plates during outages.
Vibrating or swinging electrodes	Uneven gas flow Broken electrodes	Decrease in efficiency due to reduced power input	Repair electrode.	Check electrode frequently for wear.
Inadequate level of power input (voltage too low)	High dust resistivity Excessive ash on electrodes Unusually fine particle size Inadequate power supply Inadequate sectionalization Improper rectifier and control operation Misalignment of electrodes	Reduction in efficiency	Clean electrodes; gas conditioning or alterations in temperature to reduce resistivity; increase sectionalization.	Check range of voltages frequently to make sure they are correct. *In situ* resistivity measurements.
Back corona	Ash accumulation on electrodes causes excessive sparking, requiring reduction in voltage charge.	Reduction in efficiency	Same as above	Same as above
Broken or cracked insulator or flower pot bushing leakage	Ash buildup during operation causes leakage to ground. Moisture gathered during shutdown or low-load operation	Reduction in efficiency	Clean or replace insulators and bushings	Check frequently; clean and dry as needed; check for adequate pressurization of top housing.

Summary of Problems Associated With ESPs (contd.)

Malfunction	Cause	Effect on ESP Efficency	Corrective action	Preventive Measures
Air inleakage through hoppers	From dust conveyor	Lower efficiency - dust reentrained through ESP	Seal leaks	Identify early by increase in ash concentration at bottom of exit to ESP
Air inleakage through ESP shell	Flange expansion, improper sealing of inspection hatches	Same as above, also causes intense sparking.	Seal leaks	Check frequently for corrosion around inspection doors and for flange expansion
Gas bypass around ESP: dead passage above plates and tension frame	Poor design - improper isolation of active portion of ESP	Only a small drop in eficiency unless severe	Baffling to direct gas into active ESP section	Identify early by measurement of gas flow in suspected area
Corrosion	Temperature goes below dew point	Negligible until precipitator interior plugs or plates are eaten away; air leaks may develop causing significant drops in performance.	Maintain flue gas temperature above dew point.	Energize precipitator after process has been on line for ample period to raise flue gas temperature above acid dew point.

Summary of Problems Associated With ESPs (contd.)

Malfunction	Cause	Effect on ESP Efficiency	Corrective Action	Preventive Measures
Hopper pluggage	Wires, plates and insulators fouled because of low temperature Inadequate hopper insulation *Improper maintenance* Process leaks causing excess moisture Ash-conveying system malfunction: - gas leakage - blower malfunctions - solenoid valves Material dropped into hopper from bottle weights Solenoid and timer malfunction *Suction blower filter not changed*	Reduction in efficiency	Provide proper flow of ash	Frequent checks for adequate operation of hoppers; provide heaters and/or thermal insulation to avoid moisture condensation.
Inadequate rapping, vibrators fail	Ash buildup Poor design Rappers misadjusted	Resulting buildup on electrodes may reduce efficiency	Adjust rappers with optical dust measuring instrument in ESP exit stream	Frequent checks for adequate operation of rappers
Rapping too intense	Poor design Rappers misadjusted Improper rapping force	Reentrains ash and reduces efficiency	Same as above	Same as above; reduce vibrating or impact force

Summary of Problems Associated With ESPs (contd.)

Malfunctions	Cause	Effect on ESP Efficiency	Corrective Action	Preventive Measures
Control failures	Power failure in primary system Transformer or rectifier failure: - insulation breakdown in transformer - arcing in transformer between high-voltage switch contacts - leaks or shorts in high-voltage structure - insulating field contamination	Reduced efficiency	Find source of failure and repair or replace	Pay close attention to daily readings of control room instrumentation to spot deviations from normal readings
Sparking	Inspection door ajar Boiler leaks Plugging of hoppers Dirty insulators	Reduced efficiency	Close inspection doors; repair leaks in boiler; unplug hoppers; clean insulators	Regular preventive maintenance will alleviate these problems.

APPENDIX D

Appendix D contains maintenance checklistswhich may prove useful to an operator of an electrostatic precipitator. Included here are:

Sample Electrostatic Precipitator Shift and Daily Operation Record [24];

Sample Electrostatic Precipitator Weekly External Inspection Record [24];

Sample Electrostatic Precipitator Quarterly External Inspection Record [24];

Sample Electrostatic Precipitator Annual Internal Inspection Record [24];

Sample Air Load Test Record [24];

Sample Rapper Performance Checklist [17].

Sample Electrostatic Precipitator Shift and Daily Operation Record [24]

__________ Plant __________ Unit __________ ESP

Date: __________ **Time:** __________ **Reviewed By/ Date:** __________

Gas Temp.: A____/B____ **Opacity:** A____/B____ **Gross Load:** __________

Rel. Humidity: __________ **% O_2 :** __________ **Amb. Temp.:** __________

T/R Control Set No.	Primary Volts	Secondary Amps 1	Secondary Amps 2	Secondary KVolts 1	Secondary KVolts 2	Sparks Per Minute	Remarks

Shift Checklist	Checked By (Initials)	Time	Condition (Check)		Nature of Deficiency and Corrective Action Taken
			Acceptable	Unacceptable	
Transformer-Rectifier Control Meter Readings					
Precipitator Ash Hopper Levels					
Rapper and Vibrator Controller Operation					
Daily Checklist					
HV Bus Duct Noise					
Localized Sparking					
Precipitator or Process Upsets					

Sample Electrostatic Precipitator Weekly External Inspection Record [24]

______ **Plant** ______ **Unit** ______ **ESP**

Reviewed By / Date:______

Inspection Item	Checked By (Initials)	Date	Condition (Check)		Nature of Definiency & Corrective Action Taken
			Acceptable	Unacceptable	
Check HV Transformer Oil Level and Temp.					
Inspect T-R Control & Purge Air Filters					
Check Access Door Inleakage					
Check Purge Air & Heater System Operation					
Rapper System Settings Check					
Vibrator System Settings Check					

Weekly Average As Fired Fuel Analysis: % Moisture ______
% Ash ______
% Sulfur ______
BTU / lb. ______

Rapper/Vibrator Setting Record	By (Initials)	Date	Field 1	Field 2	Field 3	Field 4	Remarks
Rapper Settings - Previous Intensity Frequency							
Rapper Settings - New Intensity Frequency							
Vibrator Settings - Previous Intensity Frequency							
Vibrator Settings - New Intensity Frequency							

<u>Sample Electrostatic Precipitator Quarterly External Inspection Record</u>[24]

_____________ Plant _____________ Unit _____________ ESP

Reviewed By / Date: _______________________

Inspection Item	By (Initials)	Date	Condition (Check)		Nature of Deficiency & Corrective Action Taken
			Acceptable	Unacceptable	
Clean Rapper, Vibrator, T-R Controls					
Rapper Switch Contact Inspection					
Vibrator Switch Contact Inspection					
Check Rapper Assembly Binding / Misalignment					
Rapper / Vibrator Boot Seals Inspection					
Rapper Plunger Condition Inspection					
Check for Defective Rappers					
Check for Defective Vibrators					
Check Vibrator Air Gap Setting					
Check Instrument Calibration					

Sample Electrostatic Precipitator Annual Internal Inspection Record[24]

________________ **Plant** ________________ **Unit** ______________ **ESP**

Inspection Item	By (Initials)	Date	Condition		Nature of Deficiency & Corrective Action Taken
			Acceptable	Unacceptable	
A. Transformer Enclosure:					
Clean and Check Insulators, Bushings					
Check Electrical Connections					
Check and Set Surge Arrestors					
B. HV Bus Duct:					
Inspect for Rust or Scaling					
Clean and Check Post Insulators					
Check for Loose Connections					
Repair Loose Bus Elbows					

Sample ESP Annual Internal Inspection Record (contd.)

Inspection Item	By (Initials)	Date	Condition		Nature of Deficiency & Corrective Action Taken
			Acceptable	Unacceptable	
C. Penthouse, Rappers, Vibrators:					
Check Centering of Upper Rapper Rod					
Clean and Check Rapper Insulators					
Inspect for Ash Accumulation Around Rods					
Check Centering of Lower Rapper Rods					
Check Insulator Heater					
Check for Water/Air Leakage in Penthouse					
Inspect Roof Penetrations for Water Leakage					
Check all HV Connections					
Clean and Check Support Insulators					
Check Collars on Vibrator Insulators					

Sample ESP Annual Internal Inspection (contd.)

Inspection Item	By (Initials)	Date	Condition		Nature of Deficiency & Corrective Action Taken
			Acceptable	Unacceptable	
D. Collecting Surface Anvil Beam:					
Inspect Hanger Rods and Clips					
Remove Packed Ash Behind Anvil Beam					
Inspect Welds of Rods to Anvil Beam					
E. Upper HT Frame Assembly:					
Inspect Welds at Hanger Pipe to Frame					
Check HT Frame Support Bolts					
Inspect Welds at Support Angles to Beam					
Check Level and Square of Frame					

Sample ESP Annual Internal Inspection (contd.)

Inspection Item	By (Initials)	Date	Condition		Nature of Deficiency & Corrective Action Taken
			Acceptable	Unacceptable	
F. Lower HT Frame Assembly					
Check Weight-Gram Rings & Align					
Check Level and Square of Frame					
Check Lower Frame Twisting					
G. Stabilization Insulators:					
Clean and Check Insulators					
H. Collecting Electrodes					
Check Ash Buildups					
Check Electrode Alignment & Spacing					
Check Plumb and Square of Components					
Inspect for Bowing or Bellying					

Sample ESP Annual Internal Inspection (contd.)

Inspection Item	By (Initials)	Date	Condition		Nature of Deficiency & Corrective Action Taken
			Acceptable	Unacceptable	
I. Discharge Electrode Assembly					
Check Ash Buildups					
Check for Broken Electrodes					
Check Alignment and Spacing					
Check Weights for Alignment & Spacing					
Check Weights for Alignment & Freedom					
J. Hopper Inspection					
Check for Ash Buildup in Upper Corners					
Check for Debris in Bottom and Valve					
Check Hopper Level Detectors					
Check Hopper Vibrators					

Sample ESP Annual Internal Inspection (contd.)

Inspection Item	By (Initials)	Date	Condition		Nature of Deficiency & Corrective Action Taken
			Acceptable	Unacceptable	
K. General:					
Inspect for Interior Corrosion					
Check Safety-Key Interlocks					
Inspect Electrical Grounding System					
Check Thermal Expansion if Required					
Check for Ash Buildup on Vanes, Ducts					
Check Transformer Oil Dielectric					

Reviewed By:

Electrical Foreman: ______________________ **Date:** __________

Mechanical Foreman: ______________________ **Date:** __________

Maintenance Supervisor: ______________________ **Date:** __________

Operating Supervisor: ______________________ **Date:** __________

Administrative Supervisor: ______________________ **Date:** __________

Plant Manager: ______________________ **Date:** __________

Sample Air Load Test Record[24]

_____________ Plant _____________ Unit

	Time: _______________	Reviewed By: _______________
	Date: _______________	Tested By: _______________
ESP: _______________	T-R Set No.: __________	Field Energized: _____________
ESP Temp.: __________	Ambient Temp.: _______	Weather Cond.: _____________

Control	Transformer Primary		Precipitator					Remarks
Manual	Amps	Volts	Milliamps 1	Milliamps 2	S/M	kV1	kV2	
Automatic								

S/M: Sparks/Minute
kV1: Kilovolts/Bushing 1

Sample Rapper Performance Checklist [17]

Collection Plate Rappers

No.	Time Interval (Minutes)	Duration (Seconds)	Work (Weight x Height)[1]	Comments
C1				
C2				
C3				
C4				
C5				
C6				
C7				
C8				
C9				
C10				
C11				
C12				
C13				
C14				
C15				
C16				
C17				
C18				
C19				
C20				

[1] For falling weight rappers

Sample Rapper Performance Checklist [17]

Discharge Wire Rappers

No.	Time Interval (Minutes)	Duration (Seconds)	Work (Weight x Height)[1]	Comments
D1				
D2				
D3				
D4				
D5				
D6				
D7				
D8				
D9				
D10				
D11				
D12				
D13				
D14				
D15				
D16				
D17				
D18				
D19				
D20				

[1] For falling weight rappers

Sample Rapper Performance Checklist[17]

Distribution Plate Rappers

No.	Time Interval (Minutes)	Duration (Seconds)	Work (Weight x Height)[1]	Comments
X1				
X2				
X3				
X4				
X5				
X6				

[1] For falling weight rappers

GLOSSARY

ABBREVIATIONS

AC - Alternating Current

ACFM - Actual Cubic Feet per Minute

APCA - Air Pollution Control Association

APCD - Air Pollution Control District

AQMD - Air Quality Management District

ARB - Air Resources Board

ASME - American Society of Mechanical Engineers

AVC - Automatic Voltage Controller

CAP - Compliance Assistance Program

CARB - California Air Resources Board

CEM - Continuous Emission Monitor

CFM - Cubic Feet per Minute

DC - Direct Current

EAA - Electrical Aerosol Analyzer

EMF - Electromotive Force

EPA - United States Environmental Protection Agency

EPRI - Electric Power Research Institute

ESP - Electrostatic Precipitator

GLOSSARY

FGD - Flue Gas Desulfurization

FW - Full Wave

GR - Grains

HT - High Tension

HV - High Voltage

HW - Half Wave

ID - Induced Draft

IGCI - Industrial Gas Cleaning Institute

JAPCA- Journal of the Air Pollution Control Association

LEL - Lower Explosive Limit

MIGI - Magnetic-Impulse Gravity-Impact

NOV - Notice of Violation

NSPS - New Source Performance Standards

PO - Permit to Operate

PEI - PEDCo Environmental Inc.

PM - Particulate Matter

PM_{10} - Particulate Matter of diameter under 10 microns

PSIA - Pounds per Square Inch (actual pressure)

RMS - Root Mean Square

SCA - Specific Collecting Area - square feet of collecting plate per 1000 acfm.

GLOSSARY

SCFM - Specific Cubic Feet per Minute

SCR - Silicon Controlled Rectifier

SoRI - Southern Research Institute

T-R - Transformer-Rectifier

V-I - Voltage vs. Current characteristics

UEL - Upper Explosive Limit

GENERAL TERMINOLOGY *

Ammeter - An instrument that measures electric current.

Anti-sneakage baffles - Internal baffle elements within the precipitator to prevent the gas from bypassing the active field or causing hopper reentrainment.

Arc - An electric discharge of substantial magnitude from the high voltage system to the grounded system, of relatively long duration and not tending to be immediately self-extinguishing.

Aspect Ratio - The effective length of an ESP divided by its effective height.

Automatic Power Control - A system using feedback signals to provide optimum power to each transformer-rectifier set while maintaining the highest efficiency possible at various loads and changing fuel conditions.

* Some of these terms appear as described in Reference 21

GLOSSARY

Back Corona - The release of positive ions caused by the electric breakdown of a gas when the resistivity of the entrained particulate is too high for sparking to occur. The effect of the positive ions is to reduce both the magnitude of particle charge and the rate of particle charging.

Bus Section - The smallest portion of a precipitator that can be independently energized.

Cell - A longitudinal row of bus sections extending from the front to the rear of a precipitator.

Chamber - A gas-tight longitudinal subdivision of a precipitator (a precipitator without any internal dividing wall is a single chamber precipitator, a precipitator with a single internal dividing wall is a two chamber precipitator, etc.).

Collection Efficiency - The weight of dust collected per unit time divided by the weight of dust entering the precipitator during the same unit time expressed in percentage. The computation is as follows:

Efficiency = {[(Dust in) - (Dust out)] / (Dust in)} x 100

Concentration of Particulate Matter - The weight of dust or mist contained in a unit of gas, eg., pounds per thousand pounds of gas, grains per actual cubic foot of gas, or grains per standard dry cubic foot (the temperature and pressure of the gas must be specified if given as volume).

Control Equipment - The necessary electrical components required to regulate the potential to the high voltage system. (Also includes meters, protection equipment, and controls for auxiliary electrical items such as rappers, heaters, etc.)

Corona - A discharge of electricity appearing as a bluish-purple glow on the surface of and adjacent to a conductor when the voltage gradient exceeds a certain critical value, but is not suffficient to cause sparking; due to ionization of the surrounding air by the high voltage. Also known as electric corona, corona discharge, and aurora.

Corona Power - The product of Precipitator Voltage and Precipitator Current, in watts.

Corona Quenching - The condition characterized by very high voltages and extremely low current.

Damper - A device installed in a duct to either regulate the gas flow by degree of closure, or to isolate a precipitator chamber from the process gas.

Dew Point - The temperature and pressure at which a gas begins to condense to a liquid.

Dielectric - A material which is an electric insulator or in which an electric field can be sustained with a minimum dissipation of power.

Effective Length - Total length of collecting surface measured in the direction of gas flow.

Effective Height - Total height of collecting surface, as measured from top to bottom.

Effective Width - Total number of gas passages multiplied by the center to center spacing of the collecting surfaces.

Effective Cross Sectional Area - Effective width times effective height.

GLOSSARY

Electric Field - One of the fundamental fields in nature, causing a charged body to be attracted to or repelled by other charged bodies. Specifically, the electric force per unit test charge.

Electric Flux - The electric lines of force in a region.

Electromagnetic Field - An electric or magnetic field, or a combination of the two, as in an electromagnetic wave.

Electromotive Force - The difference in electric potential that exists between two dissimilar electrodes immersed in the same electrolyte or otherwise connected by ionic conductors. Abbreviated EMF.

Explosive Limits - The upper and lower limits of percentage composition of a combustible gas mixed with other gases of air within which the mixture explodes when ignited. Abbreviated UEL and LEL.

Field - A lateral row of bus sections extending across the width of a precipitator and energized separately from those preceding or following.

Fly Ash - Particulate matter entrained in the flue gas leaving a fossil-fuel-fired boiler. It consists of both ash and combustible material.

Friable - Readily crumbled

Gas Passage - The lane formed by two adjacent rows of collecting plates.

Gas Velocity - A figure obtained by dividing the volume rate of flow through the precipitator by the effective cross sectional area of the precipitator.

GLOSSARY

Grounding Device - A safety device for physically grounding the high voltage system prior to personnel entering the precipitator.

Half-Wave Rectifier - A rectifier which utilizes only half of the input-alternating waveform.

High Voltage System Support Insulator - A device to physically support and electrically isolate the high voltage system from ground.

Hopper Capacity - Total volumetric capacity of hoppers measured from a plane 10" below the high voltage system to the hopper outlet flange.

Hygroscopic - Readily absorbing moisture, resulting in changes in phsical characteristics.

Impedance - A measure of the toltal opposition to current flow in an alternating current circuit, equal to the ratio of the rms electromagnetive force in the circuit to the rms current produced by it.

in situ - in the original location (Latin).

Key Interlock System - An electrical safety feature of ESPs that provides a sequence of energization or deenergization of the electrical system assuring safe access for personnel to access areas which contain exposed conductors or electrodes.

Lower weather enclosure - A non gas-tight enclosure at base of precipitators to protect hoppers from wind and/or detrimental weather conditions.

GLOSSARY

Micron - Micrometer, or 10^{-6} meter.

Ohm's Law - A fundamental law of electric circuits. Most simply stated, potential difference across a circuit equals the product of current and total resistance in the circuit.

Particle Size - The diameter of microns (micrometers) of a particular piece of particulate matter. This is often a function of the measurement technique.

Particulate Matter - Solid or liquid particles entrained in a gas stream.

Penthouse - A waterproof, gas-tight enclosure over the precipitator to contain the high voltage insulators.

Precipitator - A single precipitator is an arrangement of collecting surfaces and discharge electrodes contained within one independent casing.

Precipitator Current - The average DC current, in amperes, supplied to the bus section under consideration. Same as secondary voltage.

Precipitator Voltage - The average DC voltage supplied to the bus section under consideration, in volts. Same as secondary voltage.

Preheater - A device for preliminary heating of a material, substance, or fluid that will undergo further use of treatment by heating. With regard to ESPs, a preheater draws heat energy from the flue gas and imparts it to another part of the industrial process. An ESP used after a preheater is called a cold-side ESP.

Primary Current - Current in the transformaer primary as measured by an AC ammeter.

GLOSSARY

Primary Voltage - The voltage as indicated by AC voltmeter across the primary of the transformer.

Rectifier - A device, having an asymmetrical conduction characteristic, which is used for the conversion of an alternating current into a current having a unidirectional component.

Resistivity - The electrical resistance of a 1 cm cube of material, in units of ohm-cm.

Secondary Current - The rectified or unidirectional average current to the precipitator measured by a milliammeter in the ground leg of the rectifier.

Secondary Voltage - The average DC voltage between the high voltage system and grounded side of the precipitator.

Spark - An electric discharge from the high voltage system to the grounded system, self-extinguishing and of short duration.

Specific Corona Power - The quotient of the total Corona Power of all precipitator bus sections divided by the total gas volume, in acfm, handled by the precipitator, multiplied by 1000. Units are expressed as watts/1000 acfm.

Transformer - A device for transfering electric energy from one circuit to another by magnetic induction, usually with a change of voltage.

Transformer-Rectifier - A unit comprising a transformer for stepping up normal service voltages to the kilovolt range, and rectifier operating at high voltage to convert AC to DC.

GLOSSARY

Transmissometer - An instrument for measuring the extinction coefficient of the atmosphere and for the determination of visual range. Also known as hazemeter, transmittance meter.

Treatment Time - A figure, in seconds, obtained by dividing the effective length of the precipitator, in feet, by the gas velocity figure calculated above.

Turning Vanes - Vanes in ductwork or transition to guide the dust and gas flow through the ductwork in order to minimize pressure drop and to control the velocity and dust concentration contours.

Upper Weather Enclosure - A non gas-tight enclosure on the roof of a lprecipitator to shelter equipment (T-R sets, rappers, purge air fans, etc.) and maintenance personnel.

Voltmeter - An instrument for measuring potential differences in volts. Also known as voltage meter.

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